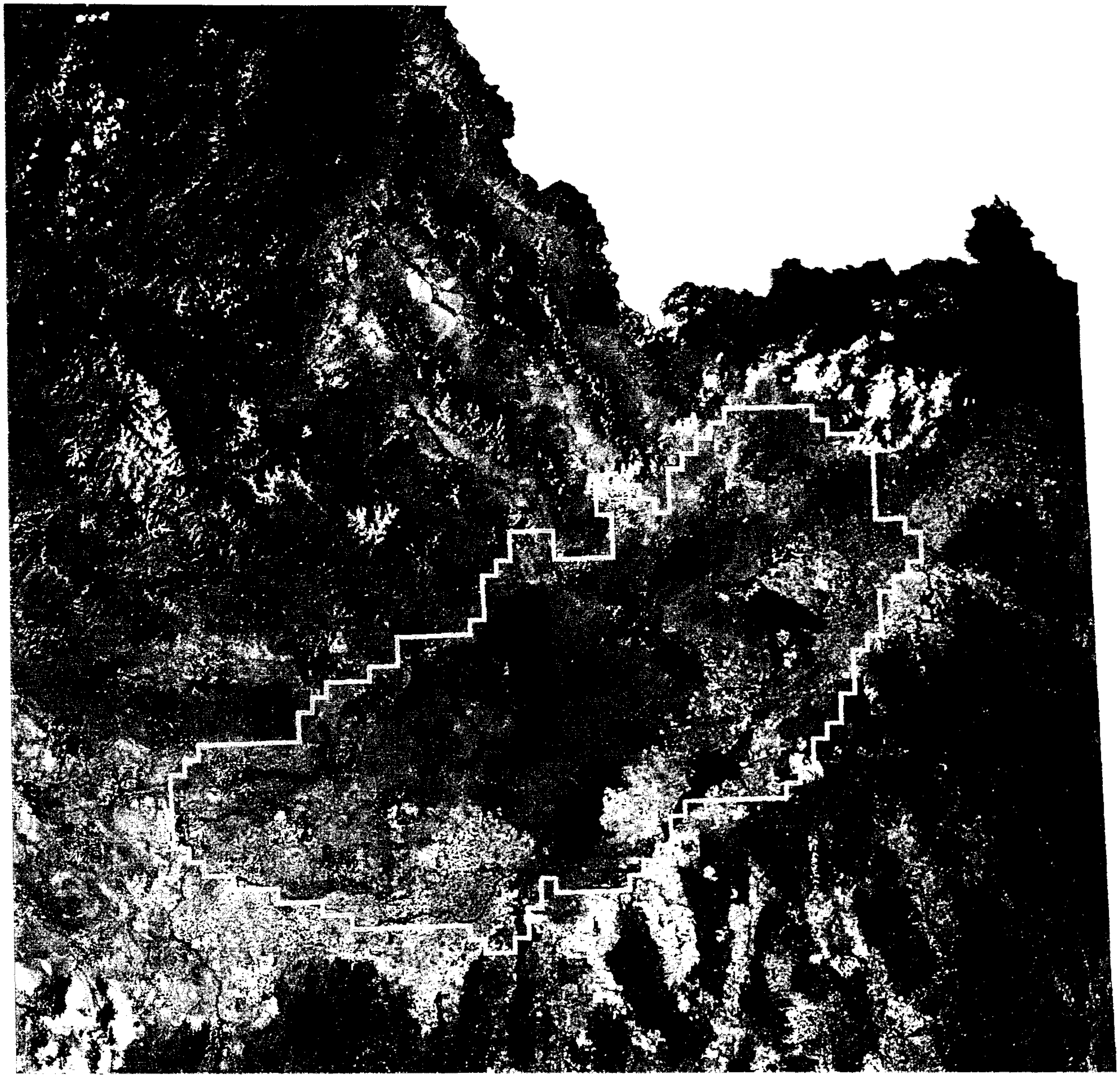
UPPER SNAKE RIVER BASIN STUDY



Idaho Department of Water Resources
Boise, Idaho

January 1997

FOREWORD

by the Idaho Technical Committee on Hydrology

The "Upper Snake River Basin Study" is a hydrologic study performed by the Idaho Department of Water Resources (IDWR) as a result of a settlement agreement between IDWR and complainants concerned with diversions from junior ground water and surface water users in the Upper Snake River Basin. A technical committee prepared the study plan that was submitted to the State of Idaho for funding. The state legislature and other entities subsequently funded the study plan with minor modifications and directed IDWR to perform the study. The Idaho Technical Committee on Hydrology (ITCH) was selected to provide technical advice and review.

IDWR conducted the study and the University of Idaho assisted with ground water modeling and managed recharge analysis. ITCH provided technical advice and review based on the study plan, detailed study tasks and conclusions. IDWR considered the technical comments and advice from ITCH and incorporated recommendations in their procedures.

The study report addresses the objectives that were developed from the list of study elements prepared by the settlement technical advisory group. Some of the study elements involved planning scenarios for other agencies; these objectives and results based on these elements are not included in this report.

Seven refined study objectives were addressed. However, to the extent specific detailed mitigation plans were expected to result from objective seven, which was "prepare possible plans for mitigation of depletion of natural flow supplies in Water District 1 resulting from ground water pumping on the ESPA", sufficient resources were not provided to fully accomplish this task. The epilogue by Karl J. Dreher, Director of the IDWR, addresses concepts for mitigation and provides an overall plan for approaching mitigation in the near term.

The results of this study are based on a regional hydrologic model and hydrologic data sets that approximate recent average conditions for the base simulation. Water supply and water use changes from the base condition were simulated for various scenarios. Because average conditions were assumed for all simulations, the modeled absolute water surface elevations and spring discharges may not necessarily portray current or future observed elevations and discharges. However, the differences in simulated responses illustrate the relative magnitude of regional impacts.

ITCH recognizes that collection and analysis of additional hydrologic and land use data for studies dealing with regional impacts would enhance confidence in results. Although the economics and time requirements of this study did not allow collection of additional data, study results are directly commensurate with the analysis and study procedures applied given the resources provided. Refined regional and local studies will require an extended analysis of additional hydrologic and land use data in relation to the geohydrologic framework of the eastern Snake Plain aquifer system.

This study identified significant impacts on aquifer levels and spring flows resulting from land use changes. The magnitude of these impacts is sufficient to require the State to develop and implement mitigation policies in the context of conjunctive surface and ground water management.

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INTRODUCTION

BACKGROUND

In July 1992, the North Side Canal Company (NSCC) and the Twin Falls Canal Company (TFCC) filed a "Complaint for Preliminary and Permanent Injunction" against the Idaho Department of Water Resources (IDWR). The complaint sought to enjoin IDWR from permitting additional consumptive diversion from ground and surface waters in the "non-trust area", the area defined by IDWR as tributary to the Snake River above Milner Dam. The purpose of this action was to stop further impacts on the natural flow available to the two canal companies. In January 1993, negotiations between the canal companies and IDWR led to a Settlement Agreement with IDWR. The agreement provided for modification and extension of an existing moratorium on permitting new water rights and a study of the interrelationships between the Snake River and the Eastern Snake Plain Aquifer (ESPA).

The agreement called for creation of a temporary technical advisory committee to prepare a detailed plan of study which would be submitted to state, federal and local entities for funding. The technical advisory committee consisted of representatives from the University of Idaho (UI), United States Bureau of Reclamation (USBR), IDWR, the Idaho Legislature, and private consultants. This team completed a list of study elements in February 1993 for submission to the 1993 Legislature. The study elements were approved by the legislature, with the exception of a conservation element, and partial funding was appropriated for a three year study to be directed by IDWR. Additional funding was provided by NSCC, TFCC, Idaho Power Company, and USBR.

The study elements developed by the technical committee are contained in Appendix A. Study elements were identified to directly respond to the Settlement Agreement concerns over development in the non-trust area above Milner Dam and its effect on natural flow users in the Upper Snake River water regulation district, Water District 1. These include defining the impacts of existing and possible future changes in ground water withdrawals and recharge.

In view of the fact that the Idaho Water Resource Board (IWRB) had previously scheduled a planning study over the ESPA, the technical committee decided to broaden this study to cover the entire aquifer, including that part of the trust area which is tributary to the Milner Dam to King Hill reach of the Snake River. Supporting this action was the fact that the Settlement Agreement acknowledged the efficiencies of expanding the study to include the entire aquifer. The committee recognized that issues parallel to the main ESPA also occur in aquifers of tributary basins. Although studies of these areas were considered beyond the scope of this study, a study element was added to prepare *plans* of study of how these areas would be addressed.

Prior to disbanding, the technical committee considered the need for peer review throughout the three year study to assure widespread acceptance and accuracy of the study results. The Idaho Technical Committee on Hydrology (ITCH) was asked to provide review and oversight as the study progressed. The ITCH group consists of representatives from several public and private agencies which have interests in hydrologic matters in Idaho. Membership is informal and flexible depending on the issues being addressed. Meetings are held periodically throughout the year in response to need. The study was reviewed by ITCH throughout its course.

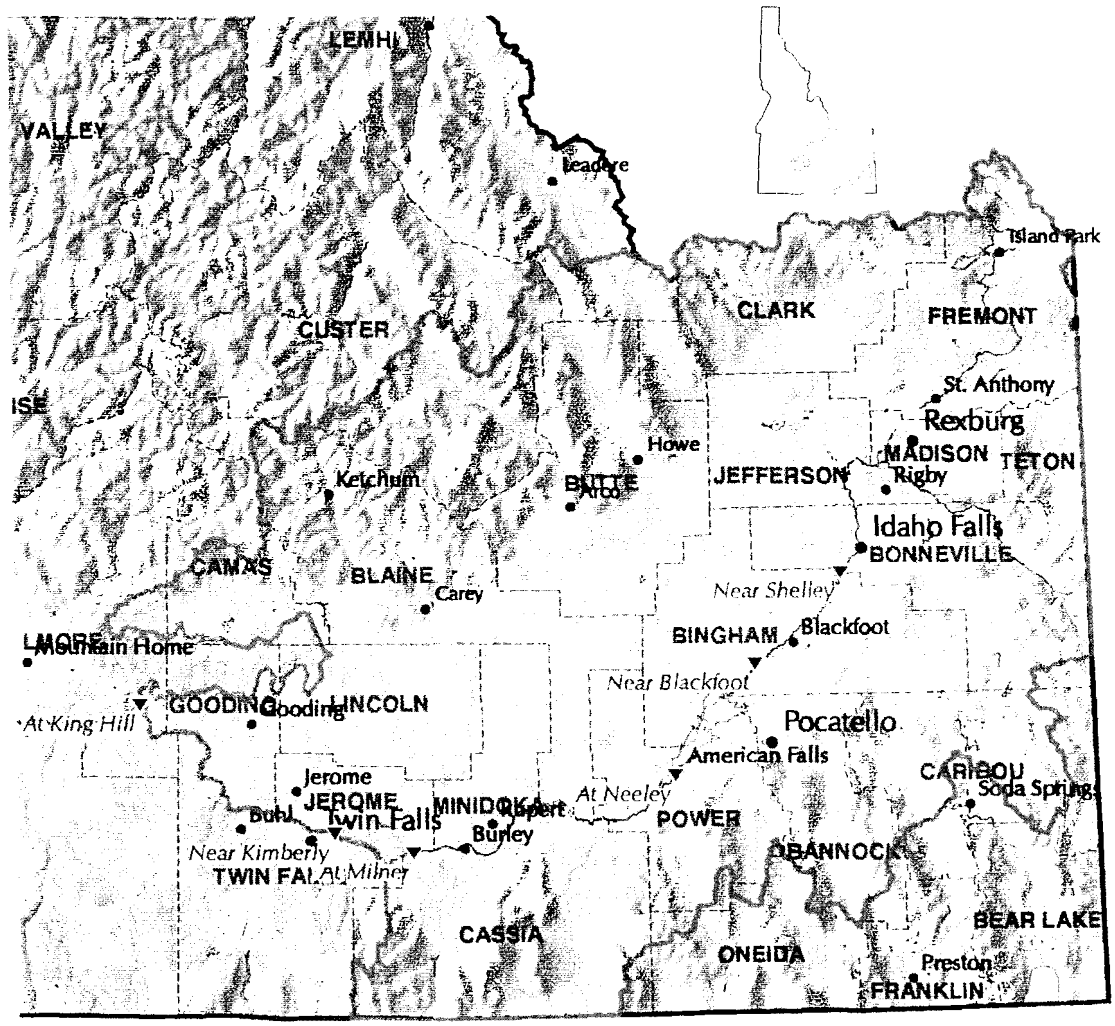
STUDY AREA

The general study area, shown in Figure 1, includes the main Snake River Basin above the King Hill gaging station. Primary emphasis is on the ESPA area tributary to the Snake River above Milner Dam (at the Milner gaging station). However, aquifer simulations include changes in uses over the entire ESPA and changes in spring outflows between Milner Dam and King Hill. Plans of study were prepared for areas tributary to the main ESPA, but no studies were completed. A detailed description of the study area is given by Garabedian, (1992). Key Snake River gaging stations referred to in this report are also shown in Figure 1.

PROBLEM

Spring discharges from the ESPA occur primarily in the Shelley to Neeley and Milner to King Hill reaches of the Snake River. Spring discharge in the Blackfoot to Neeley reach (within the Shelley to Neeley reach) increased from less than 2000 cfs in the early 1900's to a rather constant 2500 cfs from 1912 to 1980; spring discharges from Milner to King Hill increased from about 4200 cfs in the early 1900's to more than 6500 cfs in the mid-1950's, after which declines began to occur (Kjelstrom, 1986). No data are available to estimate spring discharges prior to 1900. Surface water irrigation began in the late 1800's and likely had already affected the spring discharges by 1900. Causes for recent declines in the Milner to King Hill spring discharges include the rapid growth of ground water irrigation since 1950, cessation of winter diversions by most of the Snake River canals in about 1960, and large reductions in summer diversions which began in the late 1970's. Early 1990's data indicate Milner to King Hill spring discharges in the range of 5200 cfs. Spring discharges from Shelley to Neeley are a part of the natural flow allocated by Water District 1 according to water right priorities to surface water users. Declines in spring discharges from Milner to King Hill have affected users in this reach, primarily aquaculture interests which depend on high quality spring flows for fish production. Concurrent water table declines over much of the ESPA have resulted in increased pumping head for ground water users.

Figure 1. Upper Snake River Basin Study Area



▼ *Gaging station*

OBJECTIVES

Study objectives are a composite of objectives derived from the Settlement Agreement, technical advisory committee study elements, IWRB planning needs, and ITCH recommendations. The decision to broaden the study to respond to multiple questions led IDWR to identify the following objectives:

> Estimate the effects of ground water withdrawals from the ESPA on river flows in Water District 1 and in the Thousand Springs area. Show corresponding water table elevation changes throughout the aquifer.
>
> Prepare and demonstrate a method of accounting for the effect of ground water withdrawals from the ESPA in the allocation of natural flow and use of stored water in Water District 1.
>
> Estimate the effects of reduced diversions by surface water irrigators since the mid 1970's on ground water discharges to surface sources within Water District 1 and in the Thousand Springs area and show corresponding water table elevation changes throughout the aquifer.
>
> Estimate the effects of further reductions in surface diversions on ground water discharges to surface sources within Water District 1 and in the Thousand Springs area. Show corresponding water table elevation changes throughout the aquifer.
>
> Prepare study plans including time and cost estimates for evaluating the hydrologic effects of ground water withdrawals in each major tributary basin of the ESPA.
>
> Prepare hydrologic evaluations of potential managed ground water recharge programs to the ESPA as possible mitigation to declining spring flows and water tables.
>
> Prepare possible plans for mitigation of depletion of natural flow supplies in Water District 1 resulting from ground water pumping on the ESPA.

OVERVIEW

Aquifer response to various conditions were evaluated using the IDWR/UI ESPA ground water flow model. The model was calibrated to 1980 conditions; recharge and discharge for current conditions (1982 to 1992) were then added to the model. This is discussed in the section "IDWR/UI Ground Water Flow Model". A "base study" was then run to represent conditions if recharge and withdrawal were to remain at current levels for the indefinite future. The ESPA is currently not at equilibrium, a condition when inflows and outflows balance. If inputs and withdrawals were to remain at current levels for an indefinite period, the spring outflows would adjust until they, combined with the fixed withdrawals, would come into balance with the recharge. Water table levels throughout the aquifer would adjust to a constant elevation. The base study provides a point of reference for measuring the effects of a change. It also serves as an indicator of what will happen to the aquifer and outflows if no further change occurs. Development of the base study is described in the section "ESPA Base Study".

Each "what if" simulation represents a condition altered from the base conditions. Computed differences in flow to the river between the simulation and the base study are used to estimate the effect of the withdrawals on river gains. The ground water model calculates water table elevations and ground water flow through the aquifer. Each simulation is run for many years and this output information is available at the end of any chosen period. Water table elevations for each time period are computed on a 5 km (3.1 mi) grid. Outflows are computed on the margins of this grid in discharge areas using the same grid.

To evaluate the effects of estimated historical ground water withdrawals on spring flows to the river, withdrawals were removed and a model simulation was run to a new equilibrium condition. Simulation of this "no ground water" withdrawal condition (see "No Ground Water" Study section) provides an estimate of the effects of irrigation wells on the river. This data was used to adjust the natural flow supply of the Snake River which is allocated to the various canals in the Water District 1 accounting. A description of a potential adjustment process and the resulting impact on surface users is contained in the section "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users".

Irrigation withdrawals and recharge are not static over the ESPA. The decline in recharge from surface diversions in the past 25 years (1967 to 1992) was evaluated with a model simulation. In this simulation the change from the base study was the difference between average surface diversions from 1965 to 1976 compared to average surface diversions from 1982 to 1992. Improvements in the efficiency of surface water irrigation systems are likely to continue, resulting in further declines in recharge. The section entitled "Effects of Surface Water Efficiency Improvements" discusses past and potential future changes in irrigation efficiencies and aquifer response using model simulations.

Study plans for the major basins tributary to the ESPA were developed and prioritized as low, medium or high based on the amount of current and historic ground water activity in the basin. This information is summarized in the section entitled "ESPA Tributary Basin Plans" and includes cost and labor estimates for each basin plan.

Over the past several years, there have been many proposals for reversing declining spring flows and water tables over the ESPA, as well as storing surplus runoff from the Snake River by diverting surface runoff to recharge the aquifer. The University of Idaho was retained to identify potential recharge locations using existing canals overlying the ESPA. Water supply models were used to estimate availability of surplus Snake River flows. Flows were matched with the diversion capability of existing canals to calculate potential recharge volumes. Model runs were made (see "ESPA Managed Recharge" section) to assess the impact these recharge volumes would have on spring outflows from the ESPA and corresponding water table changes.

It is important to note that *the model simulations in this study do not illustrate effects on a local level.* Because the initial set up, or calibration, of the model is dependent on data more widely spaced than the 5 km grid, it is not correct to claim accuracy of model computed elevations and outflows at each grid point. For example, there are 11 grid cells between Neeley and Minidoka, a reach of the river where gains from aquifer discharge can be computed. Computed flows at individual cells may have significant error, but the collective flow over the 11 cells adequately represents the gain to the river. Similar caution must be used when identifying changes in water table elevations. Computed water table changes are correct when taken over a range of nodes, but changes at a particular point should not be used. Simulation of various changes in water use practices in the study area were performed individually to estimate their impacts on water levels and aquifer discharges. The results for the scenarios analyzed in this study indicate the general magnitude of impacts of water use practices and are not additive or predictions of future conditions.

REVIEW OF TRUST/NON-TRUST GROUND WATER LINE

The trust/non-trust ground water line was established by IDWR hydrogeologists in 1986 as a result of the negotiated 1984 Swan Falls Agreement between Idaho Power Company and the State of Idaho. This agreement defined conditions under which Idaho Power Company's rights at Swan Falls receive natural flow from above and below the Snake River at Milner. The trust/non-trust ground water areas are shown in Figure 2. The two areas are separated by an administrative boundary which runs along an apparent ground water ridge that divides the direction of ground water movement to the Snake River above and below Milner. As shown in Figure 3, this line runs in a northeast to southwest direction across the ESPA creating the two areas. The upper section represents the area where ground water is considered tributary below Milner (trust water); the bottom section represents the area where ground water is considered tributary above Milner (non-trust water).

The trust/non-trust line was originally established based on over 400 water level measurements taken in 1980 by the USGS (Garabedian, 1992) for the Regional Aquifer System Analysis Study (RASA) and, in local areas, on other pre-1986 data. The line was first drawn perpendicular to ground water contours, but for administrative purposes was moved to follow public land survey section boundaries. The Settlement Agreement called for a review of the line using more recent data since conditions had possibly changed from 1980 to 1993. A review of the trust/non-trust line across the ESPA was included by the technical committee as a study element.

Water level data in a zone approximately 25 miles wide along the original line were plotted using 1993 USGS records. Two contour maps were drawn, one for the spring of 1993 using 66 observation wells (Figure 3), and one for the fall of 1993 using 41 wells, and the administrative trust/non-line was plotted on each. These two maps show that the 1993 contours remain relatively perpendicular to the line in both spring and fall. Although there were some minor inconsistencies, likely due to differences in data densities, neither of the two maps suggest a change from the original line is justified.

Figure 2. Trust & Non Trust Groundwater Areas

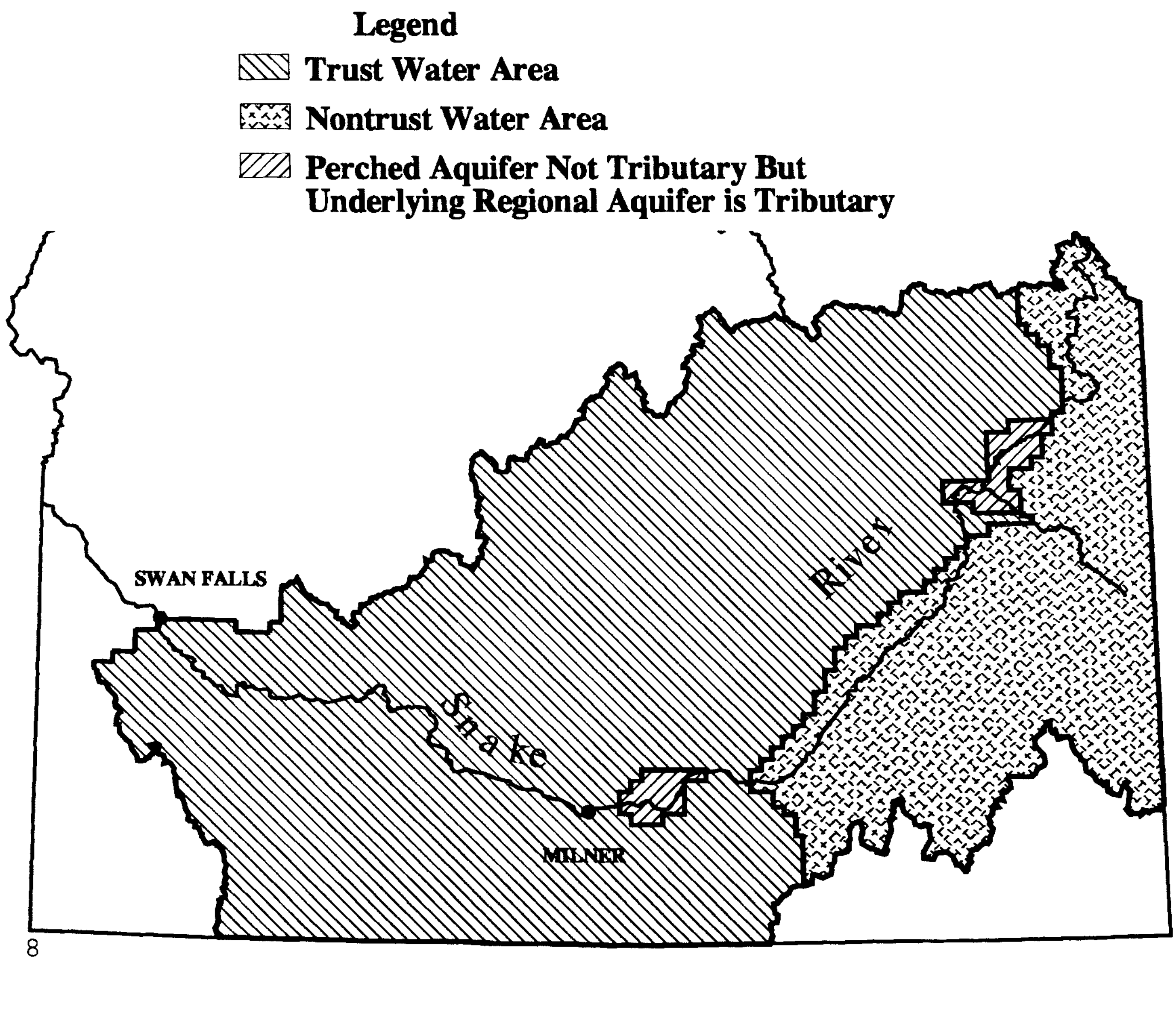
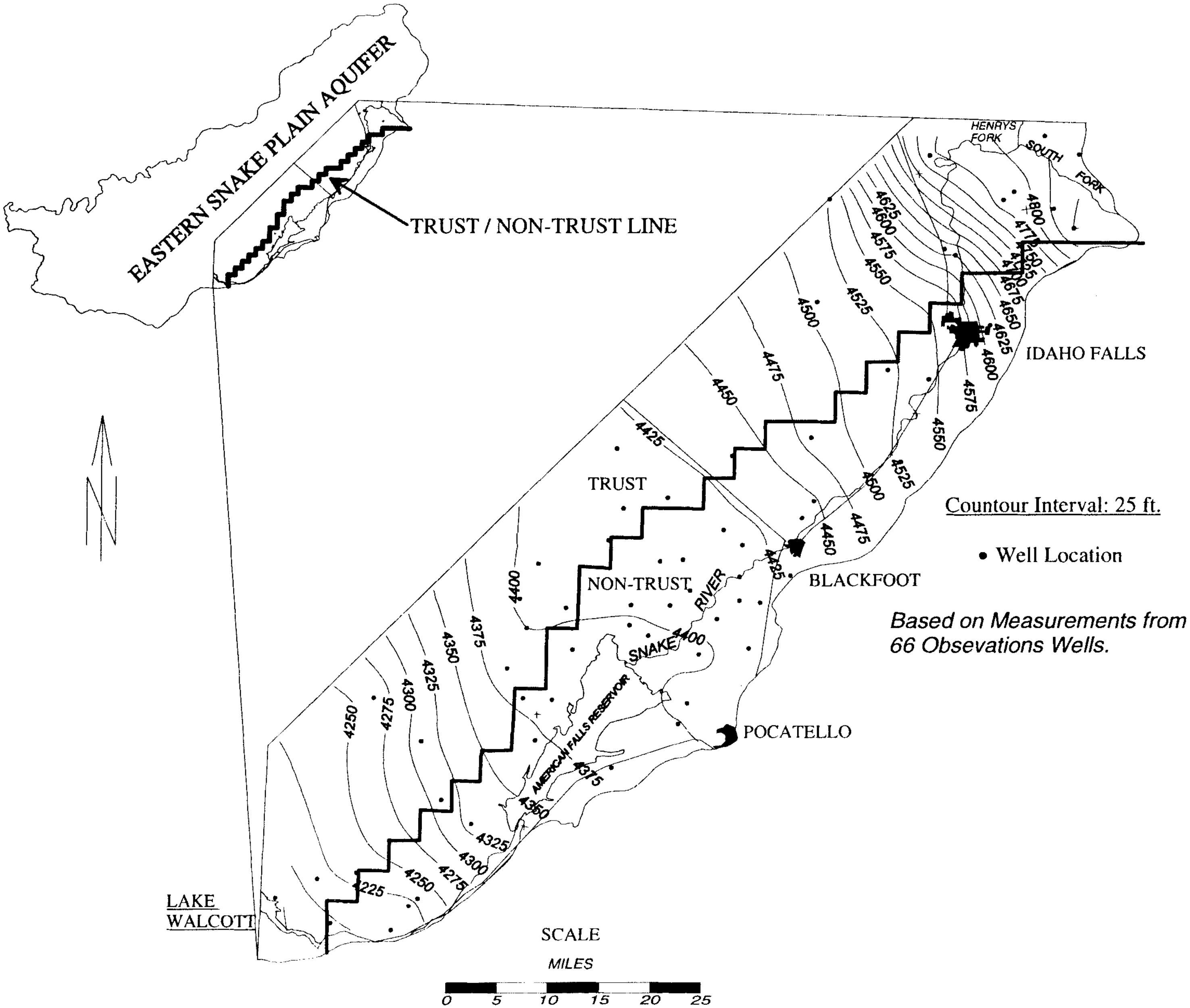


Figure 3. Trust/ Non-Trust Line Overlying ESPA
and Spring 1993 Ground Water Elevations



IDWR/UI ESPA GROUND WATER FLOW MODEL

This is a brief description of the IDWR/UI ground water flow model and its adaptation to the ESPA. A general outline description of the model is contained in Appendix B. A detailed description of the model is provided by Johnson and Brockway, 1983.

PROGRAMS

The IDWR/UI ground water flow model consists of two separate programs. The first is a recharge program which summarizes and processes input data for each component of the aquifer water balance and generates a combined recharge or discharge (net recharge) source term for each grid cell for each timestep. Water balance elements are precipitation, crop consumptive use, deep percolation from surface irrigation, tributary valley underflow and surface flow, point source pumping and injection wells, and streambed gains and losses.

A second program simulates aquifer response to net recharge, given estimates of geohydrologic parameters. The model simulates two-dimensional flow. Head values are calculated by an **iterative** solution of finite difference ground water flow equations (Johnson and Brockway, 1983). The model computes change in aquifer storage resulting from changes in ground water surface elevation and also computes reach inflow and outflow between surface streams and the aquifer. The simulation program contains a calibration routine which allows either automatic or manual adjustment of parameters in order to match water table head values, gradients, and spring discharge at reference timesteps.

MODEL BOUNDARIES

The IDWR/UI ground water flow model was adapted to the ESPA by establishing boundaries around the ESPA area previously defined by the USGS shown in Figure 4. Model boundaries do not exactly correspond to USGS ESPA boundaries for reasons of hydrologic interpretation. The encompassed area (Figure 5) was overlain with a 5 km grid and the model boundary was characterized as either fixed head (hydraulically connected to the river) or fixed flow (no flow or constant flow). Hydraulically connected fixed head cells (aquifer discharge/recharge areas) were chosen along the southern boundary of the Snake River from above American Falls Reservoir to Minidoka Reservoir and from Kimberly to King Hill. These two reaches represent the major spring discharge areas from the ESPA. All other boundaries are specified as either no flow or, where tributary valley underflow occurs, fixed flow.

Figure 4. Eastern Snake Plain Aquifer and Model Boundary

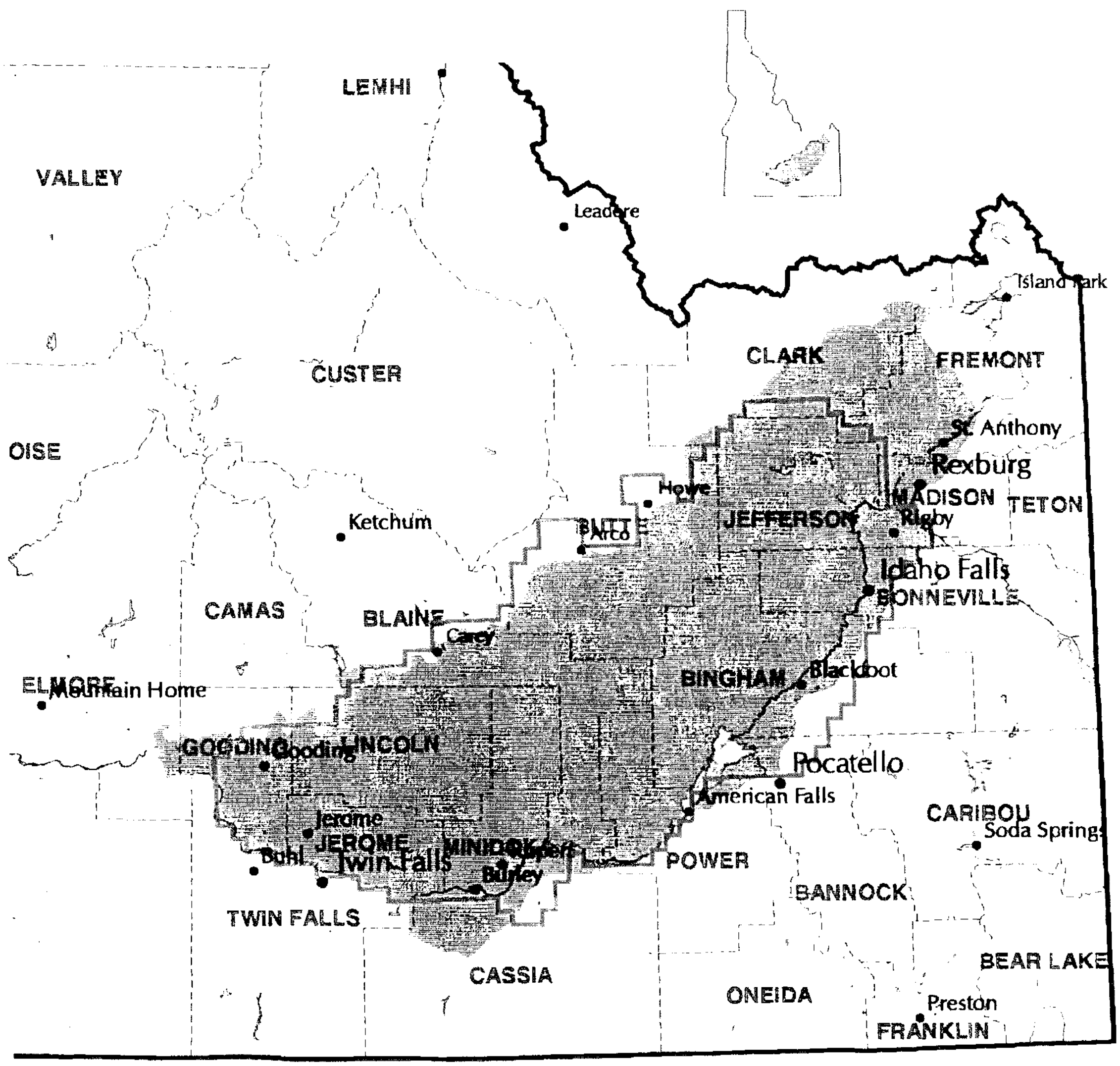
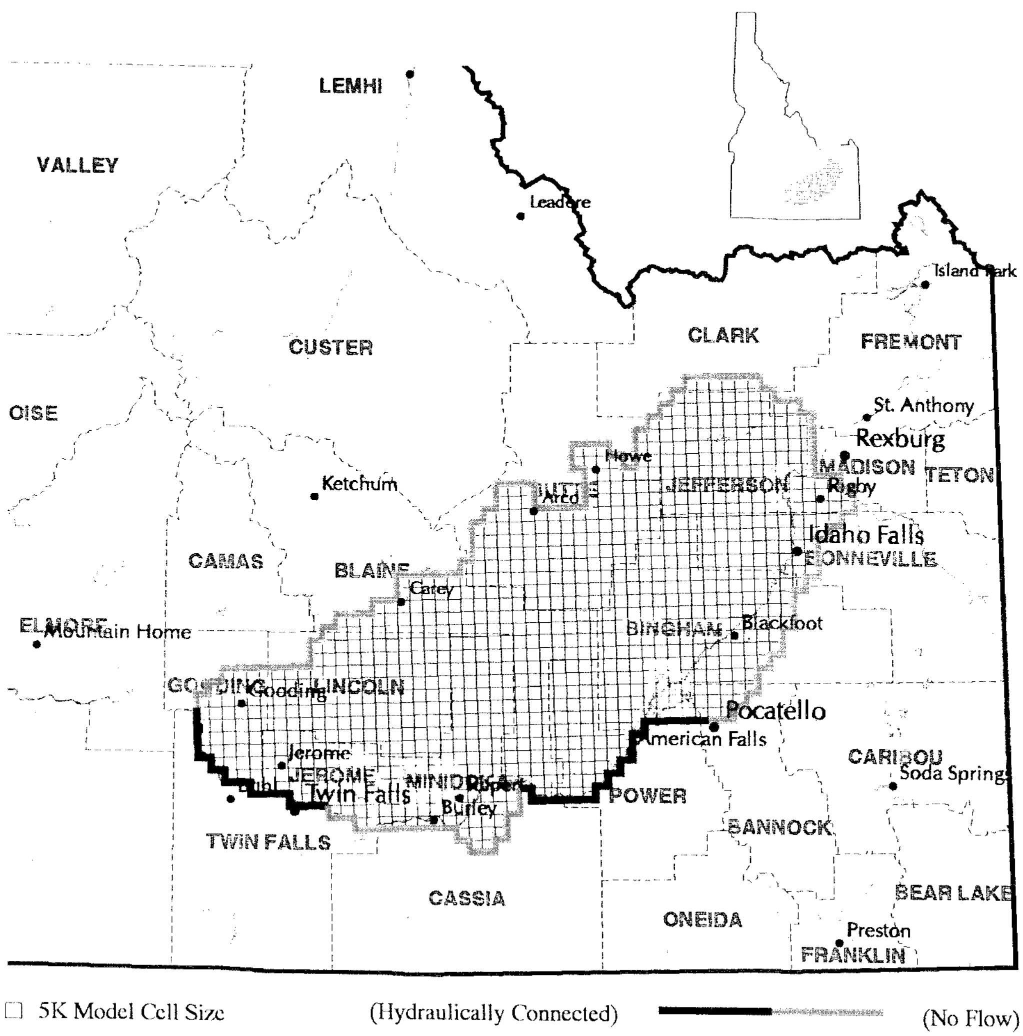


Figure 5. Eastern Snake Plain Aquifer Model



ESPA MODEL CALIBRATION

Application of the IDWR/UI ground water flow model as a management tool for the Upper Snake River basin is preceded by calibration of the model to the ESPA. The purpose of the calibration is to adjust model parameters to provide the best possible match of simulated and measured values of water table elevation and spring discharge. Previous calibrations of the model to the ESPA are described by de Sonneville (1974) and Johnson, et al (1985). The ESPA model was recalibrated for this study to more accurately simulate spring discharge. Ground water level measurement data taken for the USGS RASA studies (Garabedian, 1992) for the years 1980-81 were the most extensive and comprehensive available and were selected for model calibration.

PARAMETERS

The calibration parameters for the ESPA model are transmissivity and storage coefficient. The program compares simulated water table gradients to reference gradients and adjusts transmissivity values based on the difference. Storage coefficients are adjusted based on differences between simulated head values and reference head values. Final deviations of simulated head values from reference head values as well as deviations of simulated spring discharges at hydraulically connected cells from historic spring flows are used to evaluate the calibration.

NET RECHARGE

A combined recharge source term was generated by the recharge program for calibration using 24 half month timesteps from April 1980 through March 1981. The source term represents net recharge and is the calculated recharge or discharge to the aquifer at each grid cell for each timestep.

Year 1980 irrigated acres by water source, ground or surface water, were used to develop the net recharge due to irrigation practices for each model cell (see Appendix C). Ground water withdrawals for irrigation were set equal to the net evapotranspiration rate (see following paragraph) multiplied by the number of ground water irrigated acres in each cell. Surface water irrigated acres for each grid cell were assigned when possible to an irrigation entity (named surface water acres) associated with a specific diversion point on the river. Surface water irrigation recharge from each entity over its service area was calculated as the total diversion minus net evapotranspiration volume minus return flow. Net evapotranspiration was calculated as net evapotranspiration rate (see following paragraph) times service area acres. The recharge for surface water acres not assigned to a specific entity (unnamed surface water acres) was based on the average recharge of the named surface water irrigated acres in the surrounding cells. Surface irrigation diversions to a service area were taken from measurements reported by the Water District 1 watermaster annual report (Water District 1, 1980, 1981). Return flows were obtained from measurements taken for the USGS RASA study and estimated from miscellaneous measurements.

To compute net evapotranspiration rates, climatological data for 1980-81 was input for 11 climatic regions for each timestep based on the locations of representative weather stations. These data consist of total precipitation, average daily solar radiation, average mean daily temperature, average daytime wind speed, and average daily minimum relative humidity. Total evapotranspiration was computed for each crop type using a method developed by the University of Idaho (Allen and Brockway, 1983) with 1980-81 climatological data as input. An average evapotranspiration rate for all nodes in each climatic region was calculated based on the 1980 crop type distribution as reported by local Farm Service Agency offices. Net evapotranspiration was computed by subtracting effective precipitation from the average evapotranspiration.

Recharge from precipitation on non-irrigated areas was calculated for each climatic region as a portion of measured precipitation based on assumed effectiveness in reaching the aquifer. A part of the measured precipitation either evaporates or is used by native vegetation. Effectiveness coefficients were chosen based on predominate types of land cover in each climatic region and applied to the actual 1980-81 precipitation.

Tributary valley underflow and direct surface runoff estimates were made using previous aquifer studies and were input to the model at appropriate boundary locations. Underflow and surface runoff estimates (Table 1) total 1,605,300 acre-feet from 14 tributaries.

Several streams and canals overlying the ESPA are not hydraulically connected to the aquifer. Surface reach gains (losses) were calculated as outflow minus inflow plus diversions minus return flows plus reservoir storage change plus reservoir evaporation. Actual 1980-81 measurements were used except for return flows, which were estimated. Computed reach recharge was distributed to nodes underlying surface sources having significant values (Table 2).

Table 1. ESPA Model Tributary Basin Annual Recharge
(acre-feet per year)

Name	Underflow	Surface Flow	Total Basin Input
Big Wood	0	22,000	22,000
Silver Creek	38,000	0	38,000
Little Wood	24,000	31,000	55,000
Big Lost	114,000	51,000	165,000
Little Lost	100,000	47,000	147,000
Birch Creek	70,000	0	70,000
Blackfoot	25,000	0	25,000
Raft River	63,000	0	63,000
Portneuf	22,600	0	22,600
Medicine Lodge and Deep Creek	15,700	0	15,700
Beaver Creek	59,200	17,000	76,000
Camas and Big Bend	266,700	26,400	293,100
Warm Springs	24,700	0	24,700
Henrys Fork	588,000	0	588,000
Total	1,410,900	194,400	1,605,300

Table 2. Recharge to ESPA from Streams and Canals
May 1980 through April 1981
(acre-feet)

Snake River, Shelley to Blackfoot	111,400
Snake River, at Blackfoot to near Blackfoot	140,000
Snake River, Minidoka to Milner	281,400
Snake River, Milner to Kimberly	-23,000
Camas Creek, 18 mile to Camas	21,500
Camas Creek, Camas to Mud Lake	4,900
Mud Lake	16,400
Beaver Creek, Dubois to Camas	17,400
Little Lost River	47,700
Big Lost River	51,500
Milner Gooding Canal	146,200
Little Wood River, above Picabo to Richfield	10,600
Little Wood River Richfield to above Milder Gooding Canal	26,900
Little Wood River, above Milder Gooding Canal to near Gooding	5,900
Big Wood River, Magic Reservoir to Shoshone Canal	52,700
Big Wood River, above Thorn Creek to Gooding	-20,900
Big Wood River, Gooding to near Gooding	7,900
Total	1,066,500

The eastern portion of the ESPA is overlain by the Henrys Fork-Rigby Fan perched alluvial aquifer (HFA) which redistributes recharge within that system, eventually interacting with the deeper ESPA through leakage. A ground water flow model of the HFA (Johnson, Brockway, and Luttrell, 1985) was used to determine the recharge due to leakage to the ESPA model. A total of 766,587 acre-feet was added to nodes in the ESPA model which underlie nodes in the HFA model. A discussion of the HFA model and interaction with the ESPA model is given in Appendix D.

PROCEDURE

The calibration period was from April 1980 through March 1981 using half month timesteps. The initial values of transmissivity and storage coefficients were taken from the previous calibration based on 1966 data (Newton, 1978). The depth to water data collected by the USGS during the 1980 mass measurements (spring and fall, 1980) for the RASA study (Garabedian, 1992) were used to generate reference water tables. Spring 1981 water table elevations were developed by adjusting the spring 1980 water table based on observation well data for the spring of 1981. This provided three sets of reference head values over the ESPA on which to base the calibration.

The three sets of reference head values (spring and fall 1980, and spring 1981) and the magnitude and location of the aquifer spring outflows (reach gains) were considered more accurate than the other components of the water balance. The goal of calibration was to adjust transmissivity and storage coefficients to best match reference heads and reproduce historic aquifer discharges.

Model calibration required multiple trial simulations. Each trial simulation repeated the annual cycle of 24 timesteps until a steady state condition was reached. During the initial calibration run the transmissivity and storage coefficients were alternately adjusted based on the fit for the final timestep, number 24 (spring 1981). Using the new values, transmissivity and storage coefficients were then adjusted to begin the next annual cycle based on the closeness of fit at timestep number 11 (fall 1980). Deviations of computed head values from reference head values were insensitive to the adjustment of the storage coefficients after an initial improvement. Calibration continued by adjusting transmissivity alternately on timestep numbers 11 and 24 until there was no significant reduction in the total head value deviations from reference for both timesteps. Adjustments in the transmissivity values for specific cells were then made manually to more closely match historical spring discharges. Calibration continued until the simulated aquifer discharge and the head value deviations from reference values were considered insignificant.

The mean head value error over the entire ESPA for calibration timesteps 11 and 24 were 3.6 and 3.8 feet, respectively. These values are small when considering that the depth of the ESPA in many locations is in excess of one thousand feet. The computed outflows in the most significant aquifer discharge reaches, Shelley to Neeley and Kimberly to King Hill, were 1.93 and 4.13 million acre-feet per year, respectively. This was close to the historic outflows of 1.90 and 4.34 million acre-feet per year, respectively (Garabedian, 1992). The total change in storage calculated for the calibration period was 24.5 thousand acre feet. For comparison, the total estimated ESPA storage in the top 200 feet is 80 to 120 million acre-feet (Lindholm, 1993). Calibration resulted in the final transmissivity and storage coefficient data sets to be used in all subsequent model simulations.

ESPA BASE STUDY

A base study was run to establish a reference for estimating the magnitude of the change caused by each "what if" simulation. The ESPA base study is defined in this report as the model simulation of aquifer discharges and water table elevations which would result at equilibrium from a continuation of current average aquifer inputs and withdrawals. The following is a description of the development and use of the base study.

NET RECHARGE

A combined recharge source term was generated by the recharge program for the base study using 24 half month timesteps representing the long term average net recharge to the aquifer under present level of development and pattern of use at each grid cell for each timestep. The "present" in this report is data and information from 1992 or, in some cases, an average of a period of years preceding 1992, such as 1982 through 1992, during which conditions remained stable.

Year 1992 irrigated acres by water source, ground or surface water, were used to develop the net recharge due to irrigation practices for each model cell (Appendix C). The total 1992 irrigated acreage included in the modeled area was 1,428,961, of which 817,874 acres were irrigated with ground water. Recharge on the irrigated and non-irrigated acres was determined in the same fashion as used for the calibration (see "ESPA Model Calibration" section), except that surface irrigation diversions to a service area were determined by averaging the 1982 through 1992 measurements reported in the Water District 1 watermaster annual report (Water District 1, 1982-1992).

Net evapotranspiration in each of the 11 climatic regions for the base study was calculated using the same procedure used for the calibration except that long term averages (1951 through 1980) of climatological data were used. Crop distribution for the base study was assumed identical to that used in calibration.

Recharge from precipitation on non-irrigated areas was calculated as in the calibration except that long term averages (1951 through 1980) were used for precipitation. The tributary valley underflow estimates (Table 1) used for the calibration were also used in the base study. The stream and canal reach gains (or losses) were determined as described for the calibration except that an average of 1982 through 1992 historical gains were used. Base condition net recharge from streams and canals equaled 733,400 acre-feet (Table 3). Leakage values between the HFA and ESPA computed by the HFA model for calibration were also used in the base study.

Table 3. Base Study Recharge to ESPA from Streams and Canals
(acre-feet)

Snake River, Shelley to Blackfoot	217,300
Snake River, at Blackfoot to nr Blackfoot	97,300
Snake River, Minidoka to Milner	93,300
Snake River, Milner to Kimberly	-86,4000
Camas Creek, 18 mile to Camas	21,500
Camas Creek, Camas to Mud Lake	4,900
Mud Lake	16,400
Beaver Creek, Dubois to Camas	17,500
Little Lost River	47,700
Big Lost River	51,500
Milner Gooding Canal	17,800
Little Wood River, abv Picabo to Richfield	15,900
Little Wood River, nr Richfield to abv Milner Gooding Canal	8,300
Big Wood River, Magic Reservoir to Shoshone Canal	52,700
Big Wood River, abv Thorn Creek to Gooding	-30,100
Big Wood River, Gooding to nr Gooding	-4,700
Total	552,900

PROCEDURE

Calibrated transmissivity and storage coefficient values were used for the base study simulation. The head values of the last (24th) timestep of the calibration period (April 1980 through March 1981) were used as the initial ground water surface. The boundary configuration and grid size were the same as in the calibration (Figure 5).

The base study was developed in two steps. First, using the initial parameters from the calibration, present level net recharge values for the 24 half month timesteps were repeatedly run in sequence until an equilibrium condition was reached. Equilibrium conditions were assumed to have been reached when change in aquifer storage was less than plus or minus 30,000 ac-ft/yr. This simulation required 58 annual cycles. Ground water surface elevations from the last timestep of year 58 were then used to begin a second simulation to complete the base study. The second simulation was run for an additional 100 years using the same 24 half month inputs used for the first 58 years.

RESULTS

Decreased net recharge in 1992 as compared with 1980, resulted in initial decreases in aquifer storage of approximately 450,000 acre-feet each year. The speed at which the aquifer responds to changes is indicated by the slope of the change in annual storage (Figure 6). After 20 years the change in storage is approximately one half of the initial change. This indicates a relatively slow overall aquifer response to changes in recharge. At equilibrium conditions, represented by the 58th year of the initial simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2665 cfs and 5526 cfs, respectively (Figure 7). These discharges represent *average* spring outflows which would occur over time if no changes were made in current levels of development. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

A water budget for the ESPA modeled area at base equilibrium illustrates the relative magnitude of the combined effect of the various components of net recharge (Figure 8). About 5.2 million acre-feet per year are applied to irrigated land from surface sources (before crop evapotranspiration or deep percolation). Tributary valley underflow and leakage from the HFA total about 2.0 million acre-feet. Precipitation and stream and canal losses are 1.6 and 0.9 million acre-feet per year, respectively. Stream and canal losses include the values from Table 3 (733,400 acre-feet) plus about 250,000 acre-feet loss from the hydraulically connected reach of the Snake River from Neeley to Minidoka. On the discharge side of the water budget, evapotranspiration from the entire area of the ESPA, including surface and ground water irrigated areas as well as non-irrigated areas, is about 3.7 million acre-feet. Base condition spring discharge to the river in the Shelley to Neeley and Kimberly to King Hill reaches is approximately 1.9 and 4.0 million acre-feet, respectively.

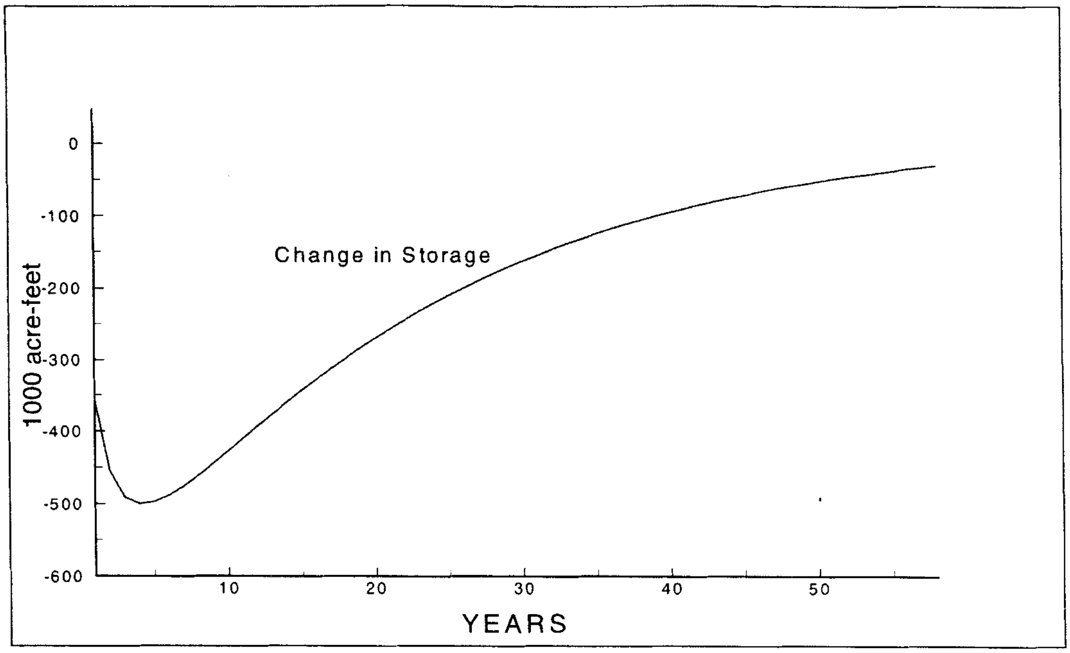


Figure 6. ESPA Change in Aquifer Storage During 58 Years of Present Condition Net Recharge

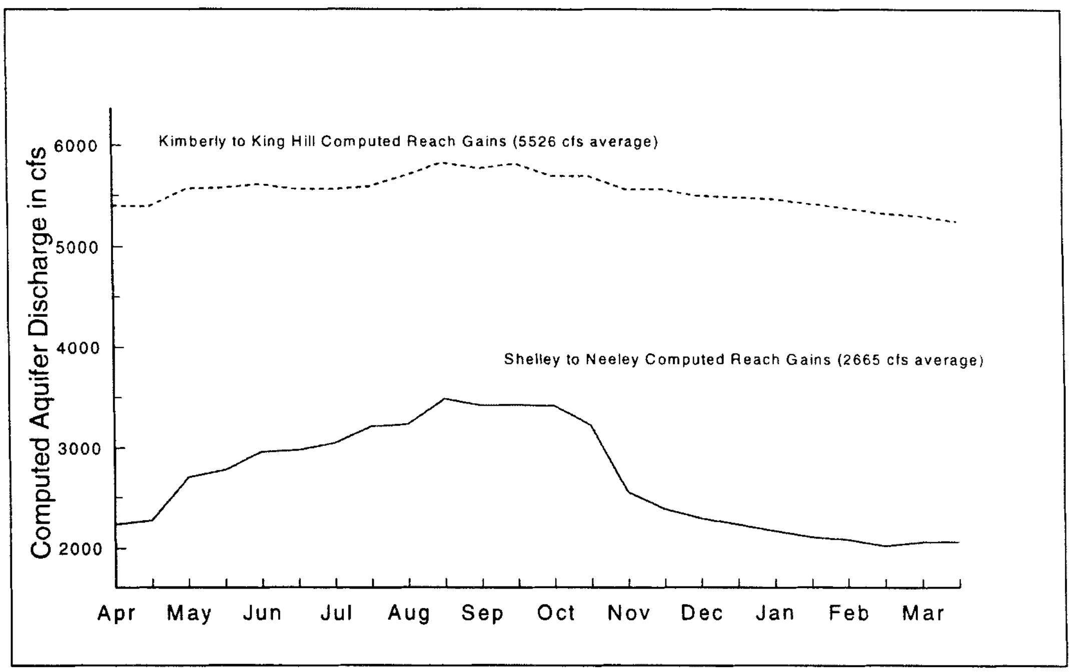


Figure 7. ESPA Aquifer Discharge for Initial Base Simulation year 58

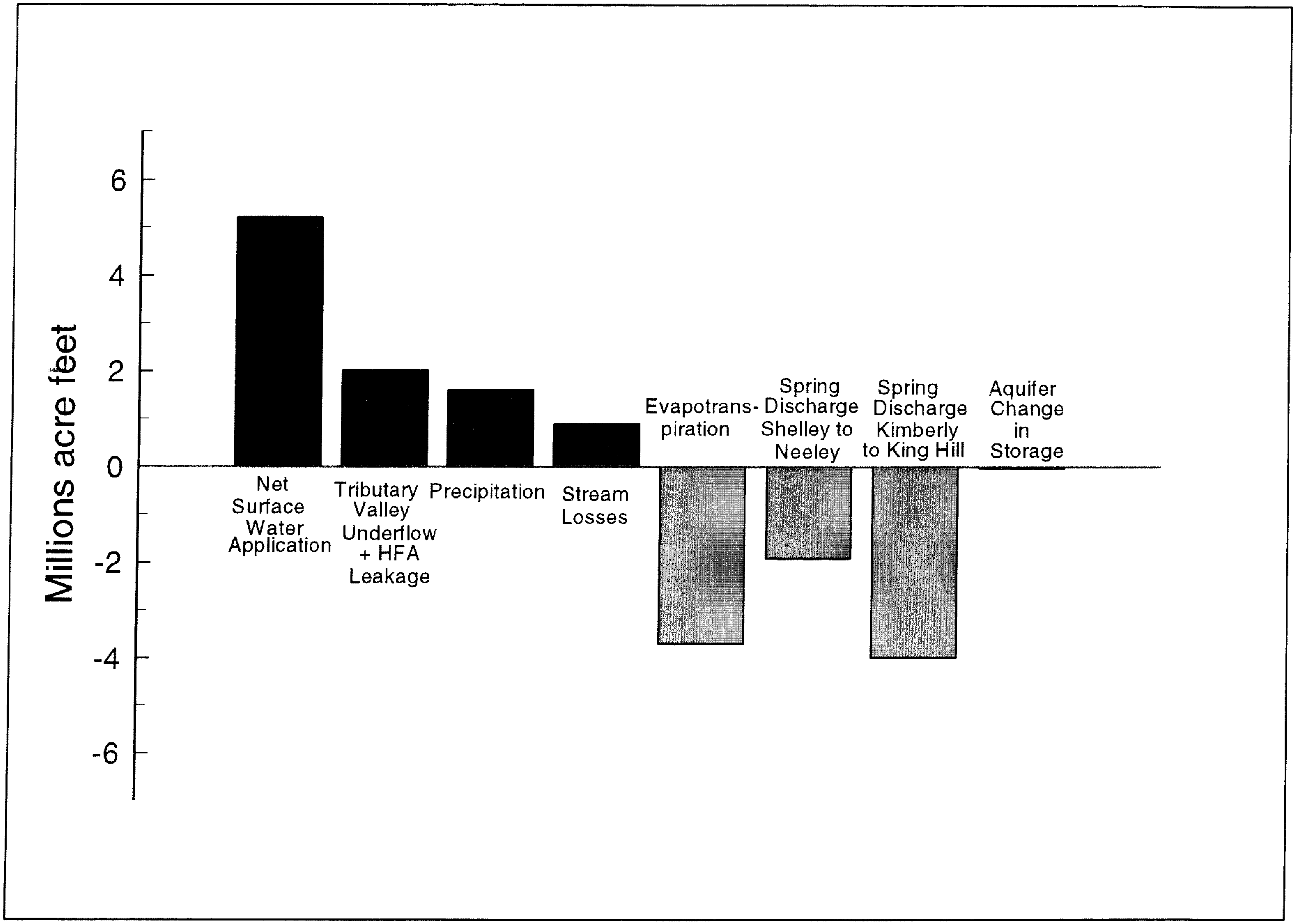


Figure 8. ESPA Modeled Area Water Budget for Base Study

USE OF 100 YEAR BASE STUDY ESPA

The base study is the 100 year simulation beyond the 58^{th} year at which equilibrium occurred using repeated annual cycles of present condition net recharge. Each "what if" study described in the remainder of this report also used the 58^{th} year as a starting point for simulation. However, unlike the base study, net recharge was changed to reflect the condition being studied. The "what if" condition was then run through repeated annual cycles until a new equilibrium was reached (change in aquifer storage less than 30,000 acre-feet per year). The changes in water table elevations and spring discharge for the new condition were then compared to the base study values at the same time and location to assess the impact of the change.

“NO GROUND WATER” STUDY

The “no ground water“ study was designed to provide a means of assessing the impact of existing ground water pumping for irrigation on ESPA spring discharges and water table elevations. A model simulation was made after removing the effect of ground water pumping over the modeled area of the ESPA. By comparing the results of this simulation with the base study, an estimate of yearly depletion of spring discharge and reduction in water table elevations from ground water irrigation was made. In general, ground water rights for irrigation are junior to surface water rights in the Upper Snake River basin. The effects of this depletion on senior surface water users in Water District 1 were estimated for an average and a low runoff year as described in the section “Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users”.

NET RECHARGE

The combined recharge source term for the “no ground water” study is the average net recharge to the ESPA at the present level of development without depletion from ground water irrigation.

Crop and land use data were the same as in the base study with the following exception: depletion due to ground water irrigated area totaling 745,000 acres was removed from net recharge. Ground water irrigated acres in and surrounding the Fort Hall Indian Reservation, 73,000 acres, were left in place under the assumption that water rights for these lands were predominately junior to down-gradient surface water rights. Net evapotranspiration and recharge on irrigated and non-irrigated acres were determined in the same manner as the base study.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the “no ground water” study, as ESPA elevations rise, leakage from the HFA is reduced. A procedure was developed for this study to model HFA leakage in response to changes in head difference using response functions. A routine was added to the ESPA model to calculate this leakage automatically using these response functions. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "no ground water" simulation. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "no ground water" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation which is indicative of the present (1992) effect of ground water depletion. The average date for ground water development in the ESPA was estimated to be 1966 (see "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users" section).

RESULTS

Increased annual net recharge of approximately 1,358,000 acre-feet due to removing junior ground water depletion as compared to base conditions resulted in initial increases in aquifer storage of more than one million acre-feet each year. The speed at which the aquifer responds to changes is indicated by the slope of the change in annual storage (Figure 9). After 25 years the annual increase in storage was 294,500 acre-feet. At 25 years approximately 70% of the impacts of the change in the recharge have occurred. Equilibrium conditions were not reached until the 100th year when aquifer change in storage was less than 30,000 acre feet per year.

After 25 years of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 3340 cfs and 6030 cfs, respectively (Figure 10). When compared to the base study, the 25 year discharge is an increase of 675 cfs and 500 cfs, respectively (Figure 11). At equilibrium conditions, represented by the 100th year of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 3500 cfs and 6140 cfs, respectively (Figure 12). When compared to the base study, the equilibrium discharge is an increase of 850 cfs and 620 cfs, respectively (Figure 13). These discharges represent estimates of *average* spring discharge and changes in spring discharge that have and will occur due to ground water depletion. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was reduced by approximately 120 cfs after 25 years and 175 cfs after 100 years due to decreased head differences between the regional system and the HFA perched system.

Figure 14 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of no pumping. Increases in ground water levels vary from less than 10 feet at the southern boundaries and western terminus of the aquifer to more than 100 feet in the vicinity of Mud Lake. The majority of the ESPA show increases in water table elevations ranging from 10 to 30 feet.

The large increase in the Mud Lake area water table is likely due to two factors. First, the area is primarily up-gradient from the Mud Lake barrier. The Mud Lake barrier is an area of low transmissivity which magnifies the response of up-gradient water levels to changes in local pumping or recharge as compared to the regional aquifer down gradient. A second cause for the large rise in Mud Lake area water table elevations is that removal of ground water depletion locally (and to a lesser extent, throughout the aquifer) reverses the current trend of declining water table elevations which has been attributed to local overdraft conditions and less underflow from the Egin Bench area.

Results of the "no ground water" study are given in terms of resulting increases in spring discharges and water table elevations after removing ground water pumping. These results are equally valid for the reverse situation to estimate the effect over time that additional ground water pumping has had on the reduction of spring discharge and decline in water table elevations.

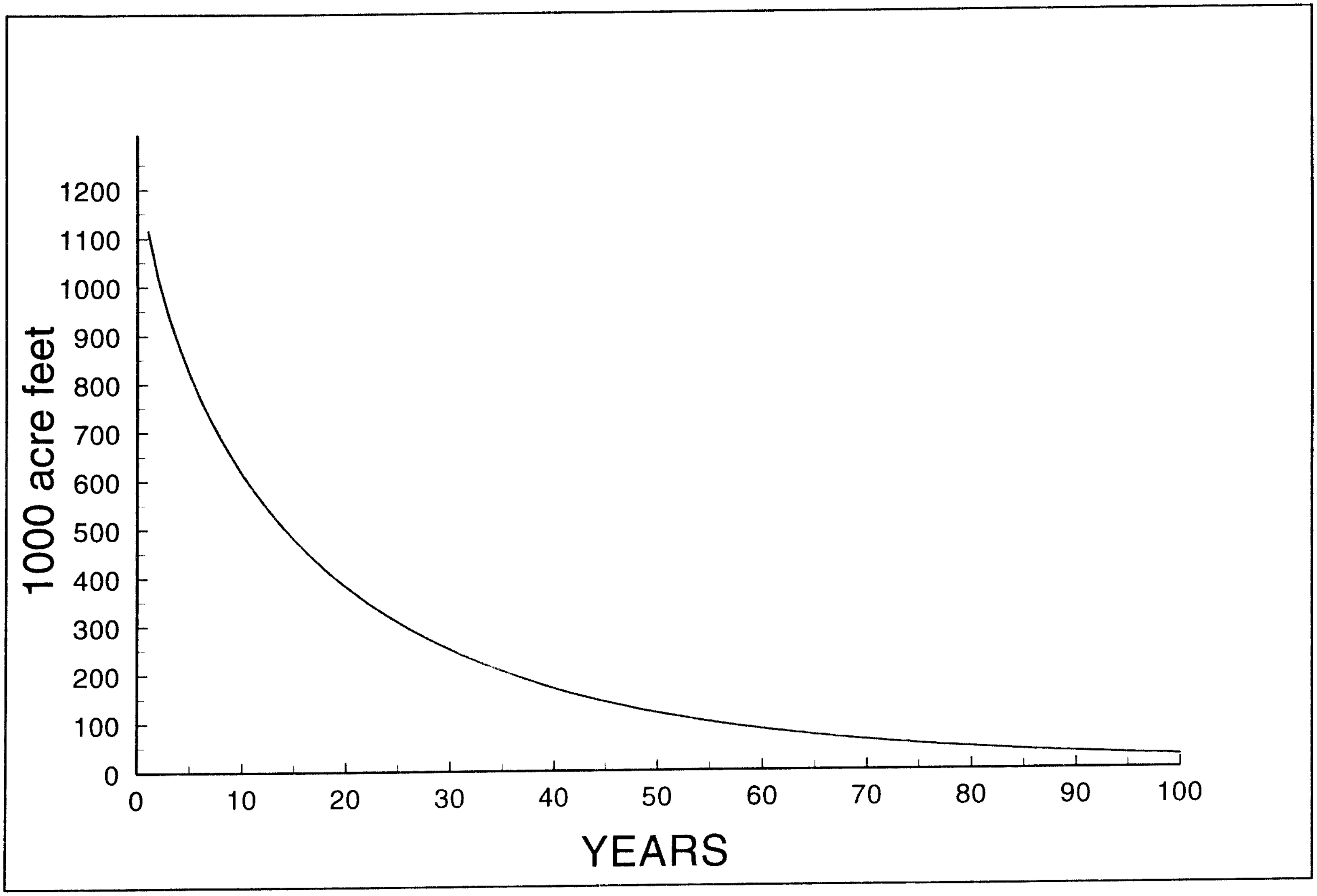


Figure 9. ESPA Change in Aquifer Storage for "No Ground Water" Study

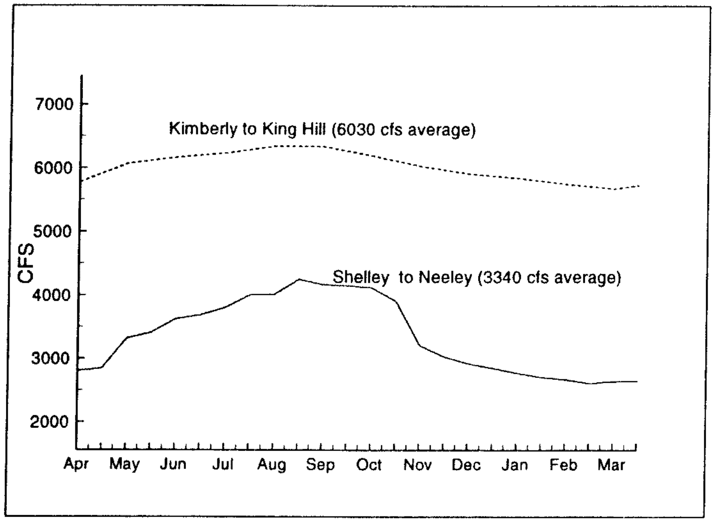


Figure 10. ESPA "No Ground Water" Study - Spring Discharge after 25 Years

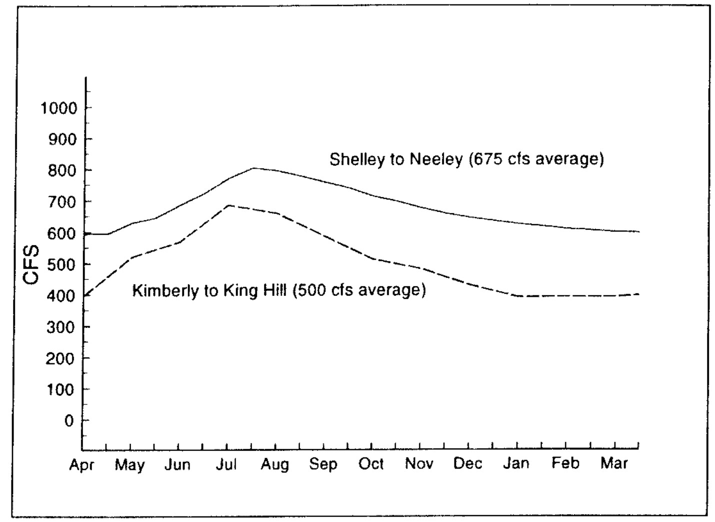


Figure 11. ESPA "No Ground Water" Study - Difference in Spring Discharge from Base after 25 Years

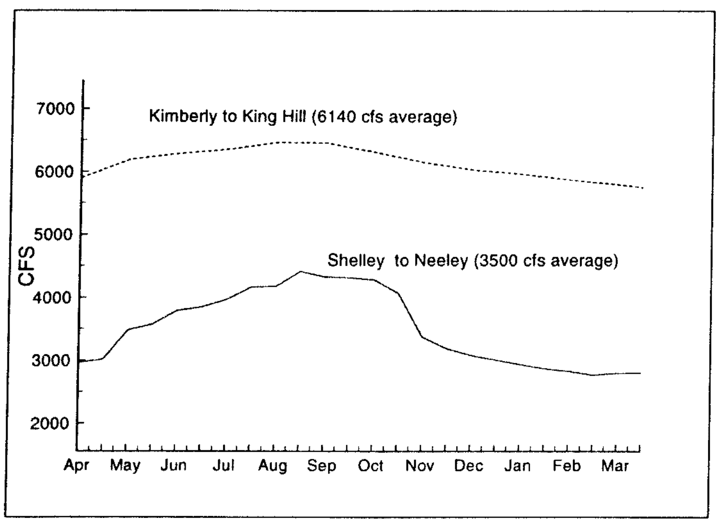


Figure 12. ESPA "No Ground Water" Study - Spring Discharge after 100 years

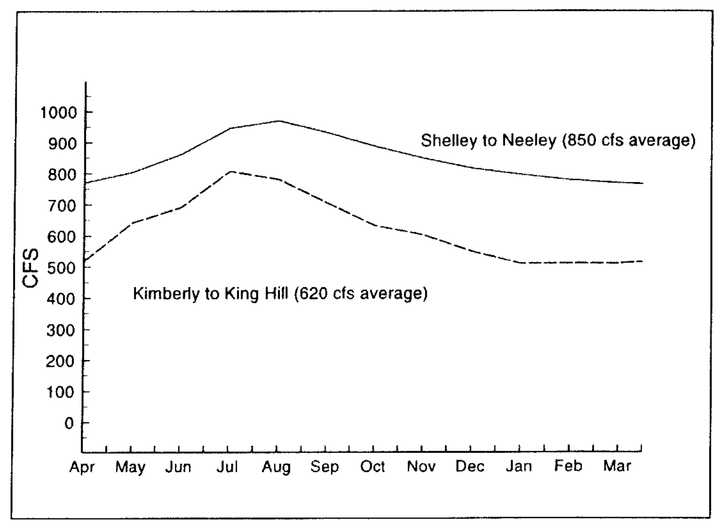
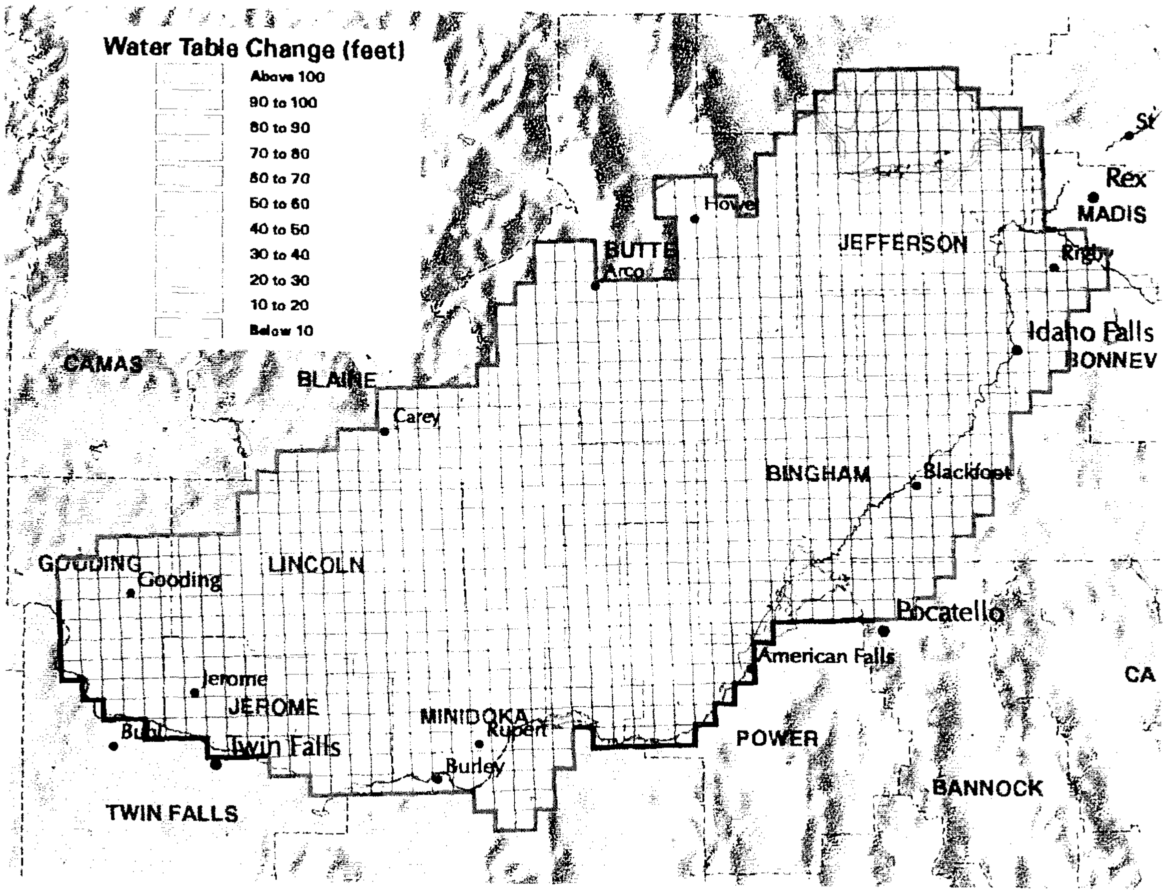


Figure 13. ESPA "No Ground Water" Study - Difference in Spring Discharge from Base after 100 Years

Figure 14. Change in Water Table Elevation After 25 years of No Pumping



□ 5K Model Cell Size (Hydraulically Connected) (No Flow)

IMPACTS OF ESPA GROUND WATER IRRIGATION ON WATER DISTRICT 1 SURFACE WATER USERS

Irrigation in the Upper Snake River basin was largely confined to surface water sources until the early 1950's. From 1950 to 1992 a steady and dramatic increase in ground water irrigation occurred. By 1992 it was estimated that more than 800,000 acres were irrigated from ground water over the modeled area of the ESPA (see Appendix D). This actually exceeded the 1992 surface water irrigated acres of less than 700,000 acres over the modeled area. Records from the IDWR water rights files indicate that from 1947 through 1992, about 700,000 acres over the ESPA were permitted or licensed for irrigation from a ground water source. The majority of surface water users in Water District 1, the Upper Snake River water regulation district, have rights senior to these ground water rights including the North Side and Twin Falls Canal Companies whose major rights date from 1900 to 1920. Reach gains to the Henrys Fork and Snake River from Shelley to Neeley, which are dependent on conditions on the ESPA, provide a significant portion of natural flow to these and other senior surface water rights. Study elements were included by the technical committee to estimate this effect on natural flow deliveries and to set up a system for use by Water District 1 to account for these effects.

WATER DISTRICT 1 ACCOUNTING

The present accounting system for allocating water has been in use in Water District 1 since 1978 (Sutter, et al, 1983). It resulted from a combination of events following the drought year of 1977 when complaints arose about numerous unmeasured and unregulated diversions. The USGS, which had provided watermaster services for many years, announced it would no longer continue these services when the current watermaster retired. A new method which could handle the complexity of over 300 diversions, as well as more than 650 water rights, was needed. The present computer-based system was developed by IDWR with help from the USBR and Water District 1. The accounting method is conceptually very simple, but becomes complex due to the large number of river reaches, diversions, reservoirs, and water rights. The accounting procedure calculates natural flows, allocates those flows in the order of priority to measured diversions, and then determines stored water used and storage supplies remaining. All computations are made on a daily basis. A more detailed description of the accounting procedure is given in Appendix E.

The method described in this section to assess the impact of junior ground water rights on senior surface rights uses the existing Water District 1 accounting procedure. The "no ground water" simulation estimates the effect of withdrawals on gains to the river. Water distribution accounting offers a means to allocate altered natural flows reflecting those effects to the various river users in accordance with water rights.

PROCEDURE

To estimate the extent of the effects of existing ground water withdrawals on surface water users it was necessary to identify the historic time period over which ground water pumping has occurred to identify a priority date that could be assigned to ground water pumping as a whole. It was considered beyond the scope of this study to assess the effects of pumping with specific priority dates. Ground water rights on file at IDWR for administrative basins 35 and 36 were compiled by year from 1940 through 1992. The cumulative acreage listed for all permits and licenses was calculated yearly for the period. The ratio of accumulated acres to the 1992 total was plotted in Figure 15. This graph illustrates the uniform development of irrigation from ground water; the half way point in this development occurred in approximately 1966. While ESPA ground rights are of varying ages, the average priority of 1966 representing all ground water diversions was chosen to estimate the effects on natural flow distribution in Water District 1. This assumption was considered reasonable since the time period during which any right later than 1940 is met under non-surplus flow conditions is very brief in all years.

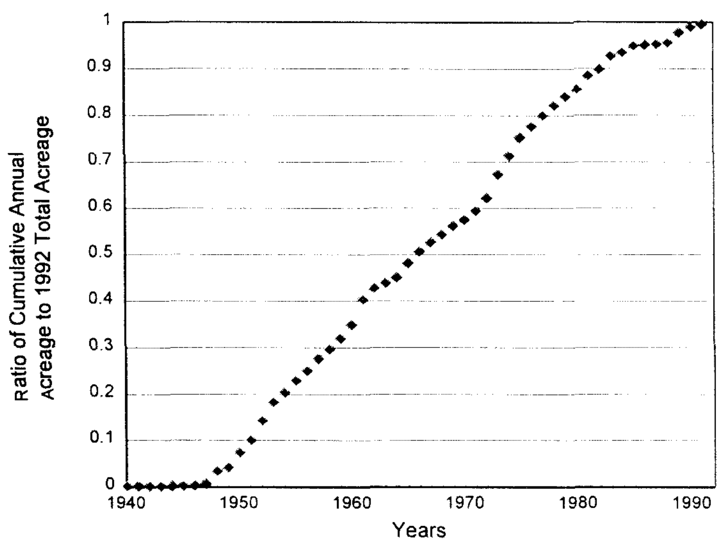


Figure 15. Cumulative Development of Ground Water Irrigation 1940-1992

Results from the "no ground water" study after the 25th year of simulation were selected as input to the Water District 1 accounting. The 25th year values would approximate the average combined effect of ground water pumping on the natural flow in 1992. Two years were chosen as examples for which to rerun the accounting with ground water depletion included. Irrigation year 1993 was chosen to illustrate the effects of an average year when most reservoir storage accounts had filled at the beginning of the irrigation season. Water distribution in 1992, a year of very poor natural flow and carryover reservoir storage in the Snake River system, was chosen to illustrate the effects during a low water year. Runoff in 1993 was approximately 100 percent of average; runoff in 1992 was approximately 50 percent of average.

From the "no ground water" study, it was shown that the gains to two reaches in Water District 1 had been significantly reduced by ground water pumping. These reaches were the lower Henrys Fork and from Shelley to Neeley on the Snake River. By placing diversions in the two affected reaches equal to the estimated reduction in gain with a 1966 water right priority, the accounting can illustrate how the various river rights might have been affected in the test years. Including these "diversions" causes the natural flow to be increased by an equal amount. The allocation process distributes this increased natural flow to the next priority right holder, thus reducing that user's stored water use. When water rights being met are all earlier in priority than the priority date of the ground water rights (1966), older surface rights benefit from greater natural flow, while the ground water diversions are accounted for as using stored water.

In the "no ground water" study, after 25 years of aquifer simulation, losses in the lower Henrys Fork were reduced by an average 121 cfs, or 87,900 acre-feet per year. In the Shelley to Neeley reach, gains to the river increased an average of 673 cfs, or 487,400 acre-feet per year. These two effects were entered into the accounting for Water District 1 as new daily diversions in the two reaches (Tables 4 and 5). Both diversions were assigned a water right priority of January 1, 1967, to represent the 1966 end of year development.

Table 4. Henrys Fork Ground Water Depletion (cfs)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	122	122	122	122	122	120	121	121	121	122	122	122
2	122	122	122	122	122	120	121	121	121	122	122	122
3	122	122	122	122	122	120	121	121	121	122	122	122
4	122	122	122	122	122	120	121	121	121	122	122	122
5	122	122	122	122	122	120	121	121	121	122	122	122
6	122	122	122	122	122	120	121	121	121	122	122	122
7	122	122	122	122	122	120	121	121	121	122	122	122
8	122	122	122	122	122	120	121	121	121	122	122	122
9	122	122	122	122	122	120	121	121	121	122	122	122
10	122	122	122	122	122	120	121	121	121	122	122	122
11	122	122	122	122	122	120	121	121	121	122	122	122
12	122	122	122	122	122	120	121	121	121	122	122	122
13	122	122	122	122	122	120	121	121	121	122	122	122
14	122	122	122	122	122	120	121	121	121	122	122	122
15	122	122	122	122	122	120	121	121	121	122	122	122
16	122	122	122	122	122	121	121	121	122	122	122	122
17	122	122	122	122	122	121	121	121	122	122	122	122
18	122	122	122	122	122	121	121	121	122	122	122	122
19	122	122	122	122	122	121	121	121	122	122	122	122
20	122	122	122	122	122	121	121	121	122	122	122	122
21	122	122	122	122	122	121	121	121	122	122	122	122
22	122	122	122	122	122	121	121	121	122	122	122	122
23	122	122	122	122	122	121	121	121	122	122	122	122
24	122	122	122	122	122	121	121	121	122	122	122	122
25	122	122	122	122	122	121	121	121	122	122	122	122
26	122	122	122	122	122	121	121	121	122	122	122	122
27	122	122	122	122	122	121	121	121	122	122	122	122
28	122	122	122	122	122	121	121	121	122	122	122	122
29	122	122	122	---	122	121	121	121	122	122	122	122
30	122	122	122	---	122	121	121	121	122	122	122	122
31	---	---	122	---	122	---	121	---	122	122	---	122
TOTAL	3662	3663	3791	3422	3788	3617	3753	3639	3767	3780	3658	3781
MEAN	122	122	122	122	122	121	121	121	122	122	122	122
MAX	122	122	122	122	122	121	121	121	122	122	122	122
MIN	122	122	122	122	122	120	121	121	121	122	122	122
AC-FT	7263	7266	7520	6787	7514	7173	7443	7218	7471	7498	7257	7499

IRRIGATION YEAR 1993 TOTAL 44320 MEAN 121 AC-FT 87908

Table 5. Shelley to Neeley Ground Water Depletion (cfs)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	676	645	625	608	599	597	629	686	771	804	778	714
2	676	645	625	608	599	594	629	686	771	795	758	714
3	676	645	625	608	599	594	629	686	771	795	758	714
4	676	645	625	608	599	594	629	686	771	795	758	714
5	676	645	625	608	599	594	629	686	771	795	758	714
6	676	645	625	608	599	594	629	686	771	795	758	714
7	676	645	625	608	599	594	629	686	771	795	758	714
8	676	645	625	608	599	594	629	686	771	795	758	714
9	676	645	625	608	599	594	629	686	771	795	758	714
10	676	645	625	608	599	594	629	686	771	795	758	714
11	676	645	625	608	599	594	629	686	771	795	758	714
12	676	645	625	608	599	594	629	686	771	795	758	714
13	676	645	625	608	599	594	629	686	771	795	758	714
14	676	645	625	608	599	594	629	686	771	795	758	714
15	658	634	625	608	599	594	629	686	771	795	758	714
16	658	634	616	604	599	594	629	686	771	795	758	714
17	658	634	616	604	597	594	646	724	804	778	739	696
18	658	634	616	604	597	594	646	724	804	778	739	696
19	658	634	616	604	597	594	646	724	804	778	739	696
20	658	634	616	604	597	594	646	724	804	778	739	696
21	658	634	616	604	597	594	646	724	804	778	739	696
22	658	634	616	604	597	594	646	724	804	778	739	696
23	658	634	616	604	597	594	646	724	804	778	739	696
24	658	634	616	604	597	594	646	724	804	778	739	696
25	658	634	616	604	597	594	646	724	804	778	739	696
26	658	634	616	604	597	594	646	724	804	778	739	696
27	658	634	616	604	597	594	646	724	804	778	739	696
28	658	634	616	604	597	594	646	724	804	778	739	696
29	658	634	616	---	597	594	646	724	804	778	739	696
30	645	634	616	---	597	594	646	724	804	778	739	696
31	---	---	616	---	597	---	646	---	804	778	---	696
TOTAL	19986	19171	19224	16973	18531	17828	19752	21106	24391	24396	22497	21864
MEAN	666	639	620	606	598	594	637	704	787	787	750	705
MAX	676	645	625	608	599	597	646	724	804	804	778	714
MIN	645	634	616	604	597	594	629	686	771	778	739	696
AC-FT	39642	38026	38130	33666	36757	35363	39179	41864	48380	48389	44622	43366

IRRIGATION YEAR 1993 TOTAL 245719 MEAN 673 AC-FT 487384

While maintaining all other hydrologic and water right input data exactly the same as actually occurred in 1993 and 1992, the accounting for both years was rerun for the entire irrigation year, beginning with November 1 through October 31 of the next year. By including the winter months, which are the months when storage reservoirs refill, effects on reservoir fill can also be determined. Reservoir fill is affected by ground water diversions since ground water depletion occurs throughout the entire year, and most reservoir storage rights in Water District 1 are older than 1966 and therefore senior to ground water pumping.

RESULTS

Results of the rerun of 1993 and 1992 water distribution accounting are significant to this study in three areas: a) reservoirs in Water District 1 will accrue more storage as a result of greater natural flow during the period when reservoir rights are being met; b) ground water users will be charged with storage equal to their effect on the natural flow of the river when rights later than 1966 are not being met; and c) surface water users will use less storage water as a result of the greater natural flow supply. The specific reservoir or surface water user affected depends on location, timing, and magnitude of natural runoff.

During the reservoir refill period for 1993 (average runoff year) and 1992 (low runoff year), the total increase in accrued reservoir storage in Water District 1 was 50,000 acre-feet and 215,000 acre-feet, respectively.

The North Side and Twin Falls Canal Companies used approximately 96,000 acre-feet and 160,000 acre-feet less storage water in 1993 and 1992, respectively. Other surface water users used a total of 67,000 acre-feet and 138,500 acre-feet less storage water in 1993 and 1992, respectively. All surface water users used a total of 163,000 acre-feet and 298,500 acre-feet less storage water in 1993 and 1992, respectively (Table 6).

Ground water users were charged with 216,000 acre-feet and 558,000 acre-feet of water that would have been available to senior water rights in 1993 and 1992, respectively.

It is important to note that the accounting simulations for 1993 and 1992 did not involve any change in actual water present in the river system, nor did it involve a change in physical operation. Diversions were substantially below normal rates of usage in 1992, and those same rates were used in the simulation. The study shows, within the context of actual diversions, how allocating the natural flow would have affected credited storage fill and charged storage use. If any changes in the accounting process were to be implemented, such as were assumed in this study, it is likely that patterns and magnitudes of use would change to adjust to actual conditions.

Table 6. Estimated Reduction in Stored Water Used by Surface Irrigators in Water District 1 with Ground Water Pumping Depletion Added to Natural Flow
(acre-feet)

User	1993	1992
North Side Canal Company	43,000	50,000
Twin Falls Canal Company	53,000	110,000
Reservoir District #2	0	17,500
Minidoka and Burley Irr. Districts	43,000	41,000
All others	24,000	80,000
TOTAL	163,000	298,500

EFFECTS OF INCREASES IN SURFACE WATER IRRIGATION EFFICIENCY

Irrigation from surface water sources now constitutes over half the total recharge to the ESPA. As irrigated agriculture developed over the ESPA this recharge rapidly displaced flow from tributary valleys as the primary aquifer recharge. Surface diversions peaked in the 1970's and dropped dramatically in the drought year of 1977 (Figure 16). Even though subsequent water years included many which were above average runoff, diversions did not return to the pre-1977 level. Diversions overlying the aquifer averaged almost 600,000 acre-feet less in the ten years following 1977 as compared to the ten year period prior to 1977. As shown by Figure 16, the four year moving average of total diversions continued to decline into the 1990's. Small, but noticeable, drops in diversions from the Big and Little Wood Rivers have also occurred in recent years.

Conversion from gravity methods to the more efficient sprinkler irrigation was undoubtedly the principal reason that diversion rates remained down, but better water management at the farm, canal, and water district levels also occurred as a result of the drought. Another factor was the 1976 Teton Dam failure which caused many irrigators to replace their destroyed gravity systems with sprinklers.

In addition to ground water pumping, increase in surface irrigation efficiency, which appears to be permanent, is the other major change causing ESPA water levels and outflows to decline. This section describes the process of estimating the effect of surface diversion reductions on the aquifer. It is also likely that the trend of increasing surface diversion efficiency will continue. This section also examines the effect of further declines in surface diversions.

"1965-1976 SURFACE WATER DIVERSIONS " STUDY

The average diversion in the twelve year period prior to 1977, 1965-76, was chosen to represent the peak of surface water irrigation. Base study diversions (1982-1992 average) were replaced by the average during that period. A one hundred year simulation of the aquifer was run to determine the response of the aquifer to this change.

NET RECHARGE

The combined recharge source term for the "1965-1976 surface water diversions" is the average net recharge to the ESPA at the present level of development with increased recharge from surface water irrigation that had occurred in the 1965-1976 time period.

Crop and land use data were the same as in the base study. Acreage irrigated by surface and ground water sources were kept at 1992 conditions (Appendix C). Net evapotranspiration and recharge on irrigated and non-irrigated acres were determined as in the base study with the exception that surface irrigation diversions to each service area were determined by averaging the 1965 through 1976 measurements reported in the Water District 1 watermaster annual report (Water District 1, 1965-1976). The average annual total of the 1965-1976 diversions overlying the ESPA was approximately 7,780,000 acre-feet as compared to the base study 1982-1992 average annual total of 6,970,000 acre-feet. The net increase in recharge to the aquifer was approximately 810,000 acre feet per year.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

Leakage from the HFA was calculated from response functions added to the ESPA model. As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the "1965-1976 surface water diversions" study, as ESPA elevations rise due to increased recharge, leakage from the HFA is reduced. A procedure was developed for this study in which HFA leakage was varied in response to changes in head difference. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "1965-1976 surface water diversions" simulation. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "1965-1976 surface water diversions" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation.

RESULTS

Increased annual net recharge of approximately 810,000 acre-feet due to increasing recharge from surface diversions as compared to base conditions resulted in initial increases in aquifer storage of more than 400,000 acre-feet each year. The speed at which the aquifer responds to these changes is indicated by the slope of the change in annual storage (Figure 17). After 25 years the annual increase in storage was approximately 100,000 acre-feet. At 25 years approximately 75% of the impacts of the change in the recharge have occurred. Equilibrium conditions were not reached until the 100th year when aquifer change in storage was approximately 30,000 acre feet per year.

After 25 years of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2950 cfs and 5900 cfs, respectively (Figure 18). When compared to the base study, the 25 year discharge is an increase of 287 cfs and 371 cfs, respectively (Figure 19). At equilibrium conditions, represented by the 100th year of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2980 cfs and 5950 cfs, respectively (Figure 20). When compared to the base study, the equilibrium discharge is an increase of 327 cfs and 423 cfs, respectively (Figure 21). These discharges represent estimates of *average* spring discharge and differences in spring discharge that would have occurred if diversions had not declined. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was reduced by approximately 48 cfs after 25 years and 62 cfs after 100 years due to decreased head differences between the regional system and the HFA perched system.

Figure 22 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of increased diversions. Increases in ground water levels vary from less than 10 feet throughout the central portion of the aquifer to more than 40 feet southeast of Burley.

Results of the "1965-1976 surface water diversions" study are given in terms of increases in spring discharges and water table elevations. These results are equally valid in estimating the effect as a reduction over time that more efficient irrigation practices has had on the reduction of spring discharge and the decline in water table elevations.

"FUTURE IRRIGATION EFFICIENCY" STUDIES

To estimate the potential impact of further reductions in surface water diversions over the ESPA, a series of additional reductions in present levels of surface water diversions were included in the net recharge to the aquifer. Base study diversions (1982-1992 average) were replaced by the appropriate lesser values. Model simulations of the aquifer were run to determine the response of the aquifer to these changes.

NET RECHARGE

The combined recharge source terms for the "future irrigation efficiency" studies are the average net recharge to the ESPA at the present level of development with decreased recharge from surface water irrigation that would occur with a 5, 10, 15 and 20 percent reduction in diversions.

Crop and land use data were the same as in the base study. Acreage irrigated by surface and ground water sources were kept at 1992 conditions (Appendix C). Net evapotranspiration and recharge on the irrigated and non-irrigated acres were determined as in the base study with the exception that surface irrigation diversions to each service area were determined by reducing the base study net diversions (1982-1992 averages) by 5, 10, 15 and 20 percent. The average annual total of the base study diversions overlying the ESPA was approximately 6,970,000 acre-feet. Net diversions were computed by deducting surface return flows of approximately 1,770,000 from total diversions. The decrease in net recharge to the aquifer after accounting for surface return flows was approximately 260,000, 520,000, 781,000, and 1,041,000 acre feet per year for the 5, 10, 15 and 20 percent reductions, respectively.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

Leakage from the HFA was calculated from response functions added to the ESPA model. As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the "future irrigation efficiency" study, as ESPA elevations fall due to the decreased recharge, leakage from the HFA is induced. A procedure was developed for this study in which HFA leakage was varied in response to changes in head difference. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "future irrigation efficiency" simulations. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "future irrigation efficiency" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached for each of the four studies. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation.

RESULTS

Decreased annual net recharge ranging from 260,000 to 1,041,000 acre-feet due to decreasing recharge from surface diversions as compared to base conditions resulted in initial decreases in aquifer storage throughout the study simulations. Equilibrium conditions for each of the studies were reached by the 100th year when aquifer change in storage was less than 30,000 acre feet per year.

After 25 years of simulation with reduced diversions of 5, 10, 15, and 20 percent, reductions in aquifer discharge from the base study in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged from 142 cfs to 565 cfs and from 132 cfs to 527 cfs, respectively (Figures 23 and 24). At equilibrium conditions, represented by the 100th year of simulation, reduction in aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged from 158 cfs and 629 cfs and 152 cfs and 607 cfs, respectively (Figures 25 and 26). These discharges represent estimates of *average* spring discharge and differences in spring discharge that would have occurred if surface water irrigators become more efficient. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was induced by amounts ranging from 22 to 87 cfs after 25 years and from 25 to 99 cfs after 100 years due to decreases in diversions of 5, 10, 15 and 20 percent, respectively as a result of head differences increases between the regional system and the HFA perched system.

Figure 27 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of a 15 percent decrease in surface water diversions. Decreases in ground water levels vary from less than 4 feet throughout the central portion of the aquifer to more than 40 feet southeast of Burley.

The estimated annual change from base study in the Shelley to Neeley and Kimberly to King Hill simulated aquifer discharge and the difference in gain to the Henrys Fork due to change in HFA leakage for all irrigation efficiency studies in this section are summarized in Table 7 for the 25th and 100th year of simulation.

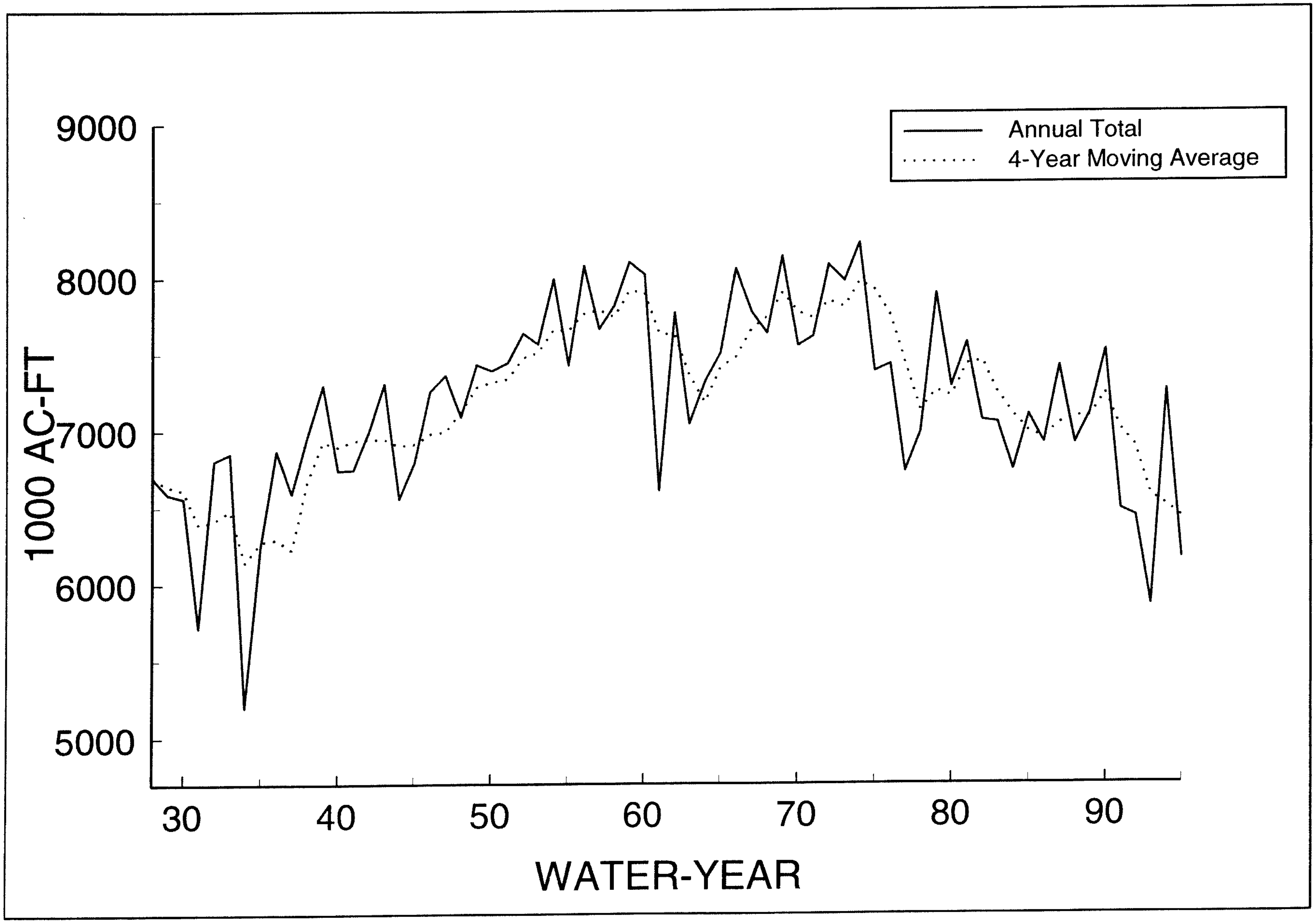


Figure 16. Sum of Historic Diversion from Surface Water Overlying the ESPA

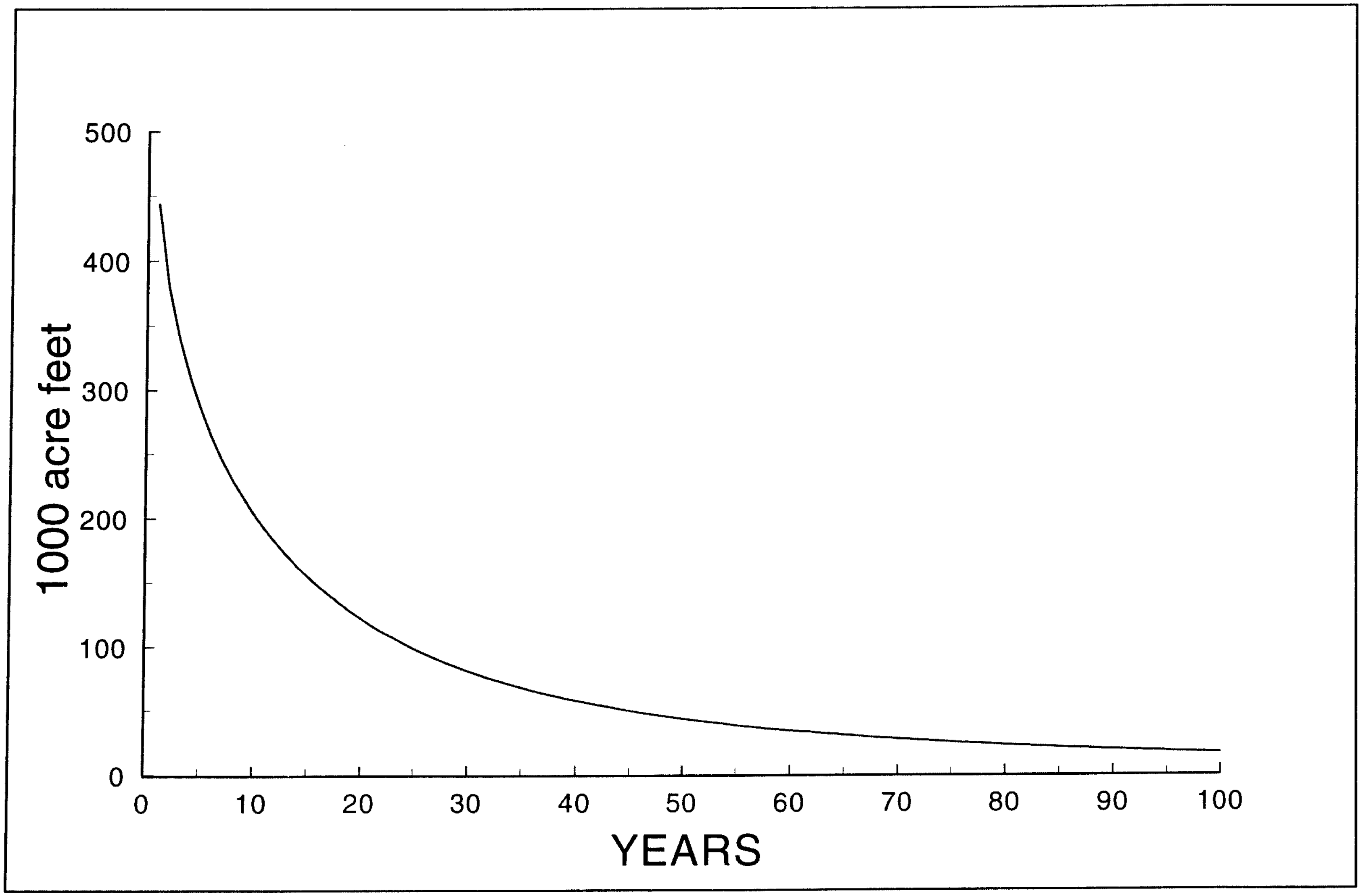


Figure 17. ESPA Change in Aquifer Storage for "1965-1966 Surface Water Diversions" Study

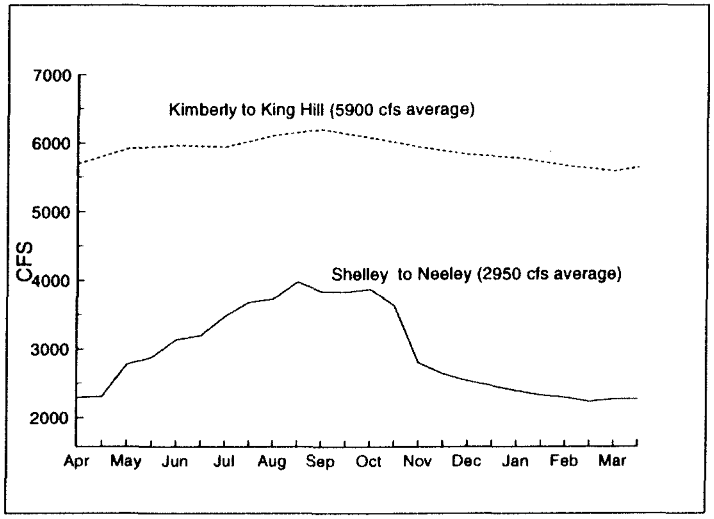


Figure 18. ESPA "1965-1976 Surface Water Diversion" Study - Spring Discharge after 25 Years

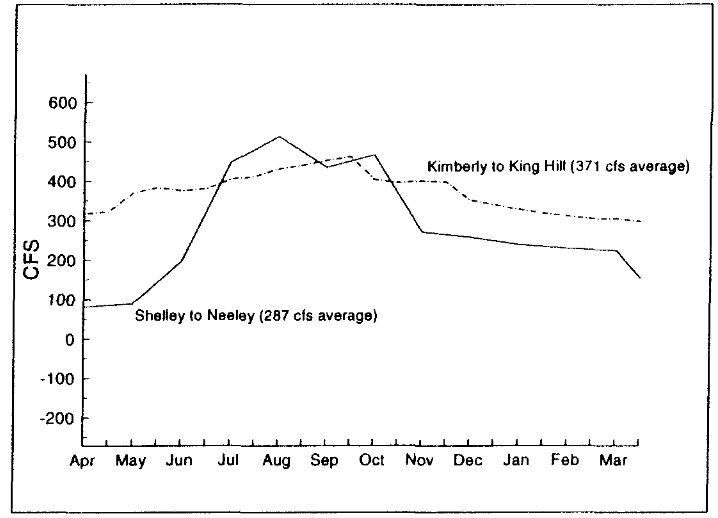


Figure 19. ESPA "1965-1976 Surface Water Diversion" Study - Difference in Spring Discharge after 25 Years

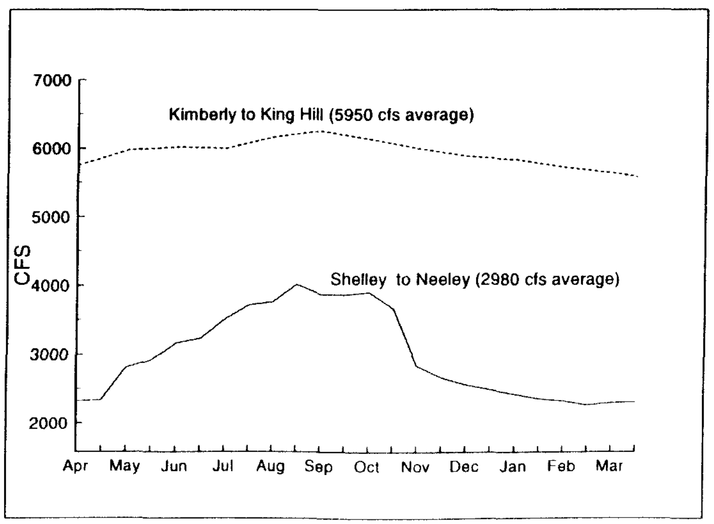


Figure 20. ESPA "1965-1976 Surface Water Diversion" Study Spring Discharge after 100 Years

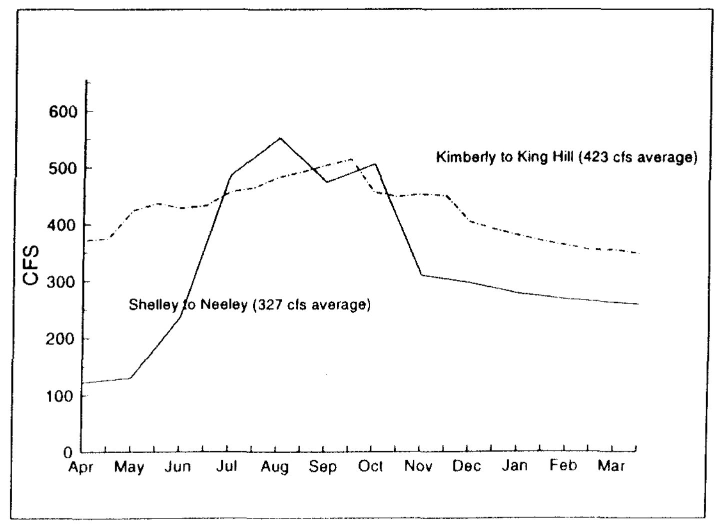
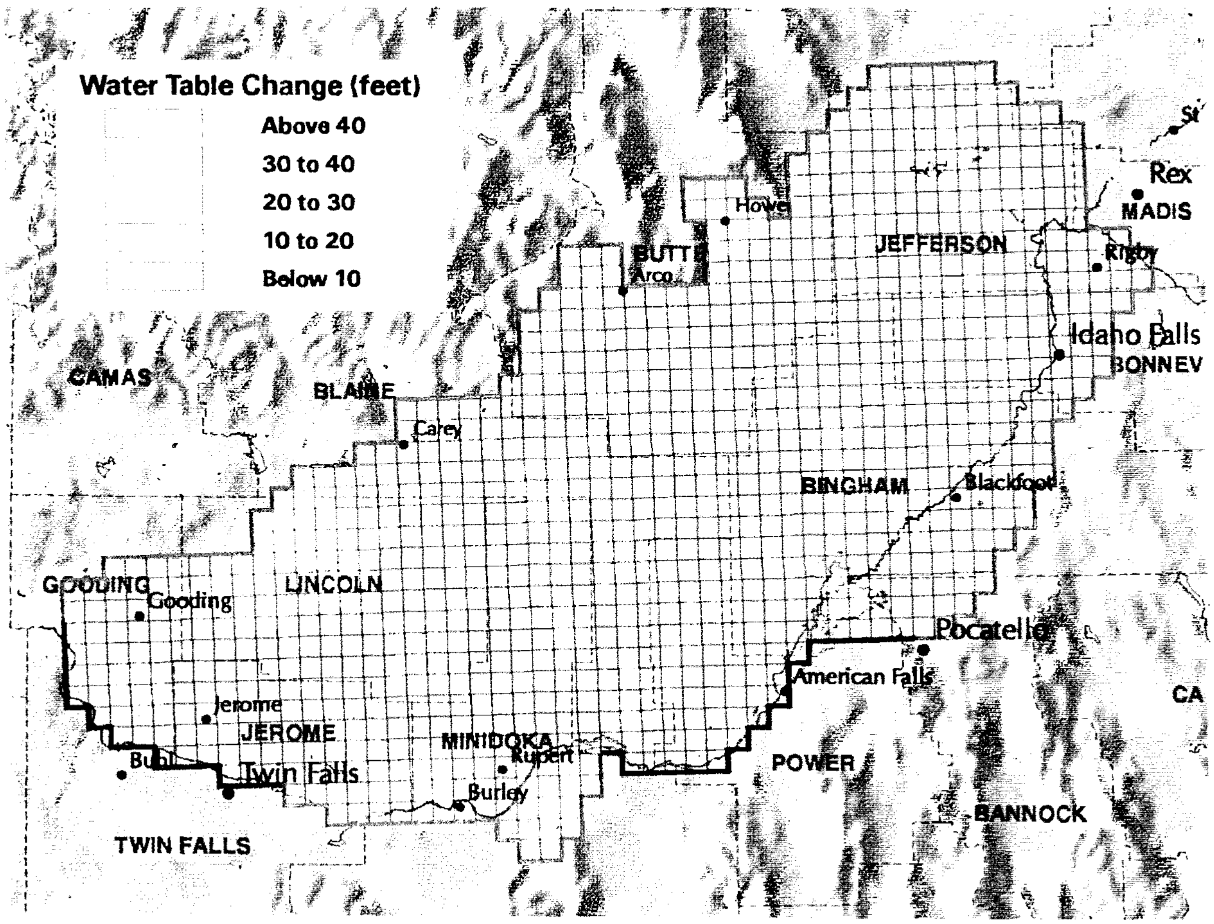


Figure 21. ESPA "1965-1976 Surface Water Diversion" Study- Difference in Spring Discharge from Base after 100 Years

Figure 22. Change in Water Table Elevation after 25 years Assuming Diversion Efficiencies from 1965 - 1976



5K Model Cell Size (Hydraulically Connected) (No Flow)

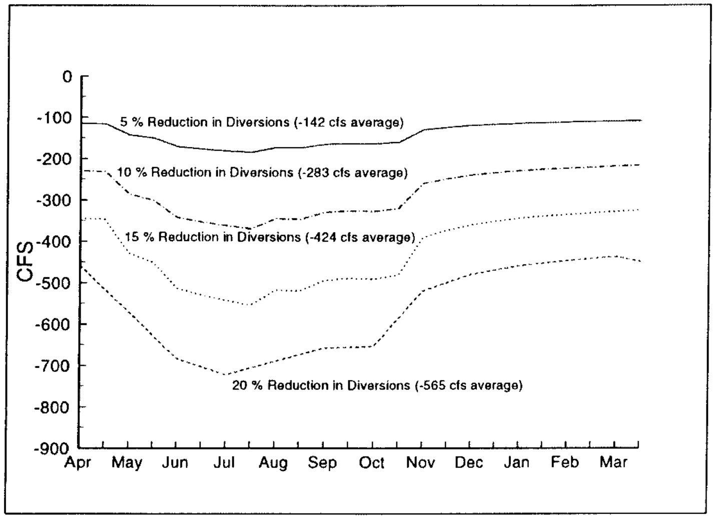


Figure 23. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Shelley to Neeley Reach from Base after 25 Years

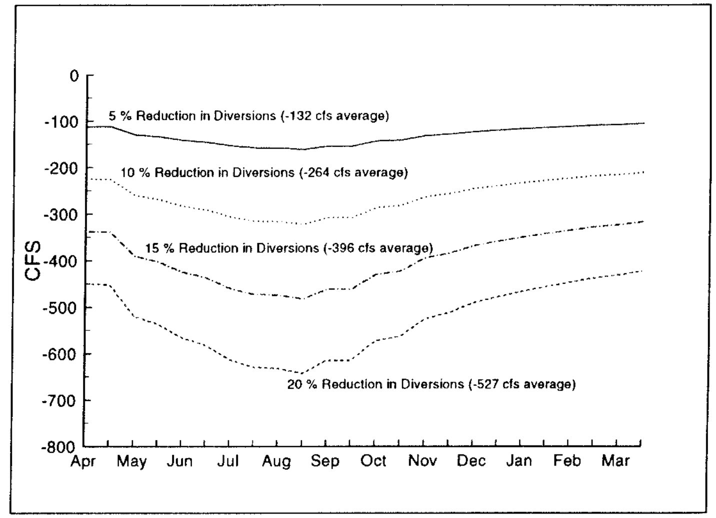


Figure 24. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Kimberly to King Hill Reach from Base after 25 Years

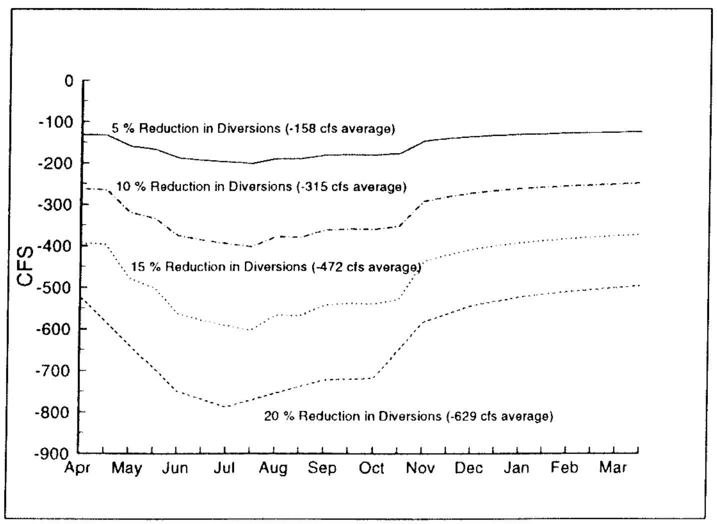


Figure 25. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Shelley to Neeley Reach from Base after 25 Years

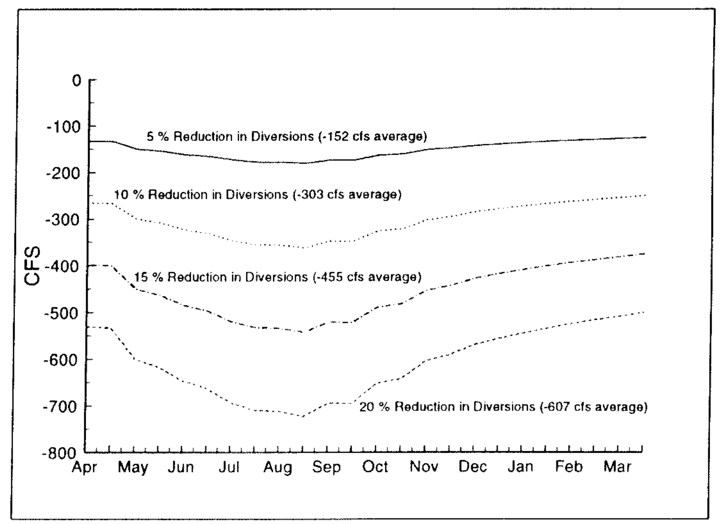


Figure 26. ESPA "Future Irrigation Efficiency " Study - Difference in Spring Discharge for Kimberly to King Hill Reach from Base after 100 Years

Figure 27. Change in Water Table Elevation after 25 years Assuming a 15 Percent Reduction in Diversion from Base Study

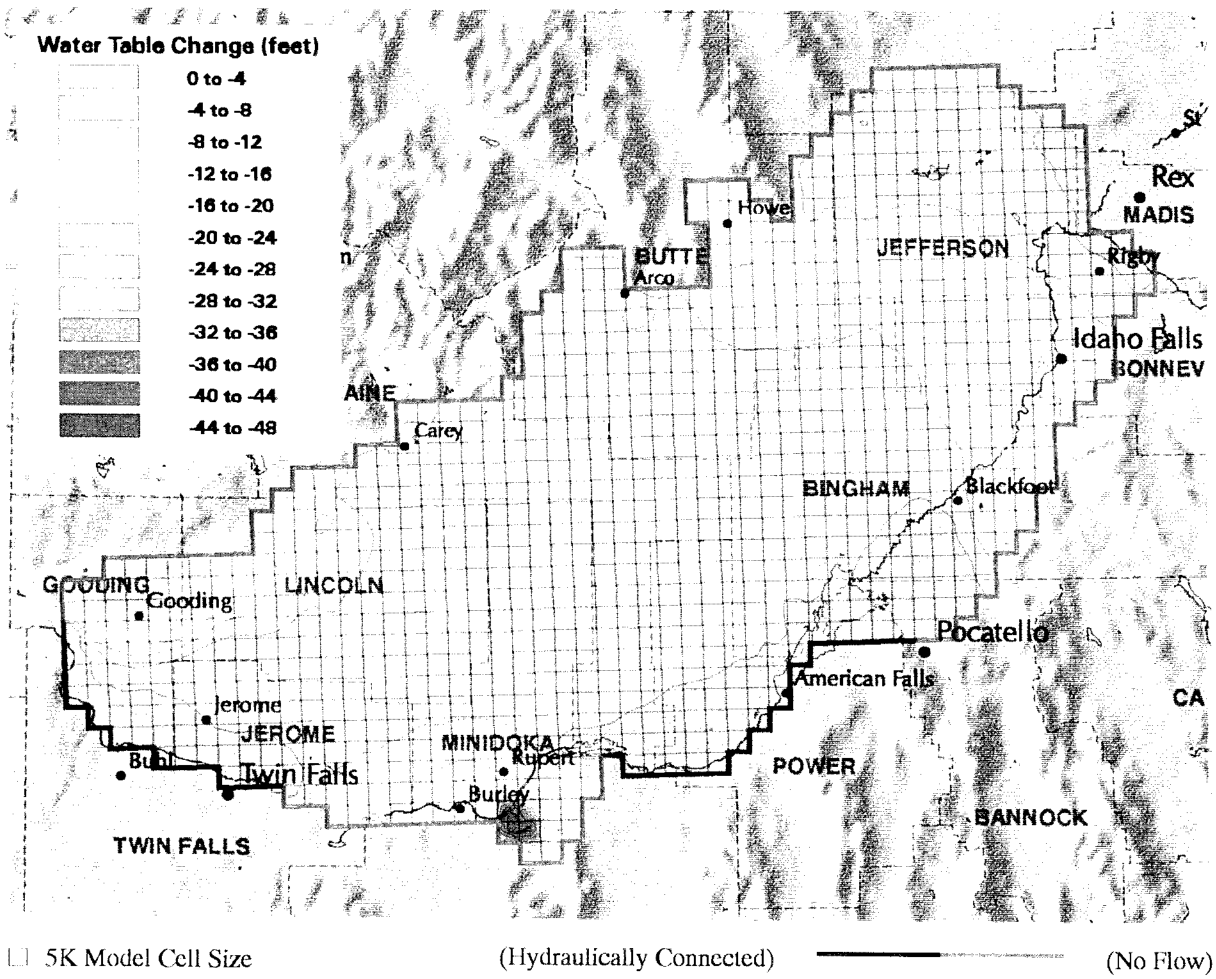


Table 7. Summary of Effects on ESPA for Irrigation Efficiency Studies

Study	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)
	After 25th Year of Simulation			After 100th Year of Simulation		
1965-76 Surface Diversions	287	371	48	327	423	62
5% Reduction Surface Diversions	-142	-132	-22	-158	-152	-25
10% Reduction Surface Diversions	-283	-264	-44	-315	-303	-50
15% Reduction Surface Diversions	-424	-396	-64	-472	-455	-75
20% Reduction Surface Diversions	-565	-527	-87	-629	-607	-99

FUTURE IRRIGATION EXPANSION

Study elements were included which called for ground water simulations to show the effects of potential new irrigation over the ESPA. One aspect of the concurrent IWRB planning study for the ESPA was to identify lands which potentially could support new irrigation development. Areas considered by the IWRB study to have the greatest potential for future irrigation development were:

Trust water area:

(a) Expansion within larger blocks of land adjacent to presently irrigated areas, most likely using a combination of ground and surface water sources. An example is northern Power County just east of the Wapi Lava Flow.

(b) Non-irrigated lands in western Clark County between Medicine Lodge and Birch Creeks. This land would be irrigated primarily with surface water from these and other tributary valleys with some ground water supplementation.

(c) In-fills within presently irrigated lands.

Non-trust water area:

(a) In-fills within presently irrigated lands using both ground and surface water sources.

Many of the acres identified as having some potential for new irrigation also have physical limitations, such as adverse climate, soil conditions, or topography that would limit irrigation expansion. Other areas are restricted by the economics of water delivery such as extreme distance from a surface source or prohibitive pumping costs associated with deep wells. The potentially irrigable land under federal administrative jurisdictions such as the Bureau of Land Management, Forest Service, INEEL, and National Park Service, and the land under tribal jurisdiction were not considered for new irrigation as were areas under state designation as a Ground Water Management Area or Critical Ground Water Area.

The conclusion is that the most practicable development scenarios available for irrigation expansion are limited to areas immediately adjacent to already irrigated tracts, primarily in-fills within the larger irrigated areas, and small "islands" of presently non-irrigated or under-irrigated lands within the area shown to be presently irrigated. These include center pivot corners, isolated small tracts, and other pieces that have not been irrigated. The acreage available for irrigation expansion in these areas is assumed to be small. In addition, lands within the trust water area of the Swan Falls Agreement present special problems of development with expansions limited to 10,000 acres per year, up to a maximum allowable development of 50,000 acres.

Based on this information it was concluded in the IWRB planning study (IWRB, 1997, in press) that the potential for irrigation of new land on the ESPA is limited to the degree that such irrigation will not be significant in the foreseeable future. Therefore no model simulations were made relative to irrigation expansion.

ESPA TRIBUTARY BASIN PLANS

The technical committee included a study element to identify and develop plans of study for areas tributary to the ESPA where ground water development may significantly affect surface water users. The committee felt that tributary issues concerning ground and surface water rights were similar to those on the ESPA itself. The committee recommended plans of study be prepared, along with associated costs and issues for each area, but considered any completed studies beyond the scope of this effort.

REVIEW OF BASIN CHARACTERISTICS

Twenty basins tributary to the ESPA were identified (Figure 28) and an intensive review of the characteristics of each basin was made. Only the tributary area lying outside the boundary of the ESPA ground water model or the HFA ground water model were included in the analysis. It was assumed that areas lying within the ESPA model area where ground water development has taken place are already accounted for in that model even though some areas may technically be considered as tributaries.

Basin information was obtained from previous studies, the IDWR water rights data base, land use data, well driller's logs, and existing water-level data. Selected physical and hydrologic data were compiled for each basin. Water rights and land use data were used to assess the level of ground water development in the basins. Plots showing annual and cumulative totals of the number of ground water rights and their diversion rates were made. Agricultural lands in each of the tributary basins were mapped. These maps were developed from 1986 Landsat classification data. Water-level hydrographs from observation wells that are representative of the basin's ground water trends were prepared. A bibliography of publications which describe the ground water hydrology of each basin was made. This information was assembled and prepared as a separate document entitled "Eastern Snake Plain Aquifer Tributary Valley Information." The document is in loose leaf form allowing updates to be made periodically as new information becomes available.

STUDY PRIORITIZATION

Due to the large number of tributary basins and limited resources available, a priority system for further study was developed based on need. The information from the basin reviews was used as input to a ranking system. The ranking system is based on the level of historic and current ground water activity in a basin. Water rights were the primary indicator used to develop each priority. When available, long-term ground water trends assisted in the ranking decisions. From these data, each of the basins were ranked according to their relative impact on the plain. Three levels of priority were identified: high, medium, and low. The criteria used to determine each of the levels are presented below.

> *High Priority* -- Total authorized ground water diversion rate exceeds 500 cfs, and a high growth rate based on historic trends (water rights, land use, and water levels).
>
> *Medium Priority* -- Total authorized ground water diversion rate between 100 cfs and 500 cfs, and a medium growth rate based on historic trends (water rights, land use, and water levels).
>
> *Low Priority* -- Total authorized ground water diversion rate less than 100 cfs, and a low growth rate based on historic trends (water rights, land use, and water levels).

The ranking for each tributary basin along with key hydrologic and water right support data are presented in Table 8. Rankings and associated information were used as a basis for developing the appropriate study methodology and can also provide a priority list for initiating tributary basin studies.

PROPOSED MODELING APPROACH

To assess the transient effects of ground water use in the tributary basins, a single-stress stream-aquifer modeling approach is proposed for each basin. Each model would simulate the effects of a single stress on each stream-aquifer system. That is, the models would simulate the effects of ground water withdrawal (or other stress, if desired) on tributary stream flow and underflow leaving the basin. The results from each model would be input into the ESPA ground water model and then the Snake River surface water accounting model (see "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users" section) to determine the effect on users in Water District 1.

MODFLOW, a finite-difference ground-water flow model developed by McDonald and Harbaugh (1988), will be used to simulate stream-aquifer conditions in each of the twenty tributary basins. Utilizing the principle of superposition described by Reilly, et. al. (1987), the model will simulate changes in tributary stream flow and underflow leaving each basin due to ground water withdrawal. Recharge to the aquifer from stream losses will be the only recharge component in each simulation. Other sources of recharge such as infiltration from local precipitation and unconsumed irrigation water will not be included in the simulations. Simulations will be conducted with flat water tables and no aquifer recharge or discharge. Under these conditions there is no gradient between the stream and aquifer and, therefore, no water movement between them.

Advantages of Proposed Method:

- Offers a simplified and direct technique for simulating the time-varied effects of ground water withdrawal on stream flow and underflow leaving each basin.

- Model results will provide estimates of the impacts of tributary basin ground water development on Upper Snake River surface water users.

- Offers a standardized approach for evaluating impacts of ground-water withdrawal on stream flow and underflow for each tributary basin, regardless of its size and level of development. Modeling results from each basin can be easily and equally compared when utilizing the same method.

- Although the methodology used for each basin is the same, the level of effort for data collecting and compiling, and model construction can vary. Estimated number of man-months to study Birch Creek, a low priority basin, is three; whereas, Portneuf River, a high priority basin, is six.

- Less time intensive and costly than a conventional multi-stress model. Preliminary estimates of time and cost savings are approximately 50 percent.

- If interest and resources justify using a conventional multi-stress modeling approach for any basin, the results from the single-stress method will be a necessary and useful step in conducting a more in-depth study of a basin. There would be no duplication of effort.

PROPOSED PROJECT METHODOLOGY

Each tributary basin project will be composed of six steps. These include: data collection, data compilation, model construction, model validation, model utilization, and final report. Study elements of each step are outlined below. The proposed study plan as applied to each tributary basin could be revised based on the particularities of each basin or as additional information is developed.

Data Collection:

- Review previous studies to understand relationship between stream-aquifer system.

- Review well driller's reports for principal lithologies, depth of aquifer penetration, and specific capacity data.

- If appropriate, conduct aquifer tests.

- Measure depth to water in selected wells if water-level data are unavailable.

- Conduct field survey of tributary stream to determine average streambed widths and depths for hydraulically connected stream-aquifer reaches.

- If appropriate, perform stream flow reach gain and loss measurements.

- Determine the percentages of ground water irrigated crops from field surveys, Soil Conservation Service, and other sources.

Data Compilation:

- Create digital base map of tributary basin (include township and range lines, major streams, highways, towns, and boundaries of ESPA model and HFA model).

- Determine physical boundaries of aquifer from geologic maps and previous studies.

- Determine areal distribution of principal lithologies that comprise aquifer from well driller's reports and previous studies.

- Digitize boundaries of aquifer and principal lithologies.

- Estimate apparent thickness of principal lithologies of aquifer using maximum depths of penetration from well driller's reports.

- Compute values of hydraulic conductivity and specific yield for principal lithologies from specific capacity and aquifer test data.

- Compute values of transmissivity for each principal lithology from mean values of hydraulic conductivity and estimated thickness.

- Compile irrigated acreage data from best available sources (USBR, Landsat imagery, etc.) for basin. Overlay adjudication water right data to identify acreage irrigated with ground water.

- Compute average monthly ground water depletion rates from estimates of ground water irrigated acreage, percentages of each ground water irrigated crop, and the average monthly consumptive use for each crop.

- Create profile of tributary stream stage and ground water surface using topographic maps and depth to water data.

- Determine locations of hydraulically connected stream-aquifer reaches from profile.

- Determine lengths of hydraulically connected stream-aquifer reaches.

- Estimate streambed thickness using 20 percent of the estimated stream width. Top and bottom of the streambed are based on estimated stream depth and estimated streambed thickness.

- If stream flow reach gain and loss data are available, compute values of streambed hydraulic conductivity. If not, assume a value one tenth of the mean hydraulic conductivity computed for the aquifer.

- Compute values of streambed hydraulic conductance for each hydraulically connected stream-aquifer reach using computed or estimated values of streambed hydraulic conductivity.

- Estimate mean monthly stream flow for hydraulically connected stream-aquifer reaches using data from continuous stream gages, reach lengths, and reach gain and loss measurements.

Model Construction:

- Define model as a transient simulation with the number of annual cycles corresponding to the median age of ground water rights for the basin. Each annual cycle will consist of seven stress periods representing the six months of irrigation from April to September and one six-month period of non-irrigation from October to March. The total number of stress periods will be equal to the number of annual cycles times seven.

- Define model grid with axes oriented sub-parallel to principal direction of ground water flow.

- Define model as a single layer with isotropic and confined conditions. (Anticipated drawdown will be small to relative aquifer thickness, so confined conditions should adequately simulate the unconfined conditions that prevail in the aquifer).

- Define grid cells corresponding to aquifer boundaries. Grid cells corresponding to impermeable boundaries of aquifer will be assigned no flow. Grid cells corresponding to the ESPA and/or HFA model boundaries will be assigned general head using values for hydraulic conductance based on those models.

- Define aquifer properties for each grid cell using mean values of transmissivity and specific yield for the principal aquifer lithologies.

- Set initial head for all grid cells equal to zero.

- Define average monthly ground water depletion rates for corresponding grid cells for each stress period. Hold values constant for same monthly stress periods throughout entire simulation. Set stress periods that correspond to six-month non-irrigation period equal to zero.

- Define stream-aquifer parameters for corresponding grid cells using computed values for streambed hydraulic conductance, stream flow, and top and bottom of the streambed. Stream stage will be set equal to zero. Hold values constant for all parameters throughout entire simulation.

Model Validation:

Most model simulations that include all components of stress (recharge and discharge) to an aquifer are commonly tested or validated by means of a calibration process. This process generally entails comparing simulated water levels with measured water levels and adjusting the hydraulic properties of the aquifer and stream bed until an acceptable match occurs. Since the single-stress modeling approach does not simulate the complete hydrologic system, alternate methods must be used to validate the results of these models. They include:

- Evaluate overall water balance from model simulation to assure that each component is within reasonable limits.

- Perform sensitivity analyses of stream-aquifer parameters by adjusting these values to within reasonable hydrologic limits and evaluating the range in simulated stream depletion.

- When possible, compare simulated stream losses and gains with measured values and adjust stream-aquifer parameters accordingly.

- Evaluate simulated values for underflow depletion at general head boundary of model to assure that they are within a reasonable percentage of estimated total basin underflow.

Model Utilization:

Modeling results for a tributary basin will be input into the ESPA ground water model and the Snake River surface water accounting model in order to distribute the estimated impact on surface water users throughout Upper Snake River basin (Water District 1). The following procedure will be used:

- Input values for underflow depletion and/or surface recharge from the tributary basin model into the ESPA and/or HFA ground water models at the corresponding boundary grid cells.
- Run ESPA model to obtain simulated impacts on reach gains to the Snake River. Compare results with base study to determine depletion in reach gains.
- Input reach gain depletion and/or stream depletion into the Water District 1 accounting model to estimate changes in availability of natural surface flow and resulting changes in storage water accrual and use for surface water users (see procedure described in "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users" section).

FINAL REPORT

A final report will be prepared for each tributary basin study. The reports will include descriptions of the general hydrogeology, data collection and compilation effort, model construction and validation steps, and final model utilization. Report figures will include maps of the study area, general geology, well locations and stream gaging sites, ground water irrigated lands, model grid and boundary conditions. Graphs showing ground water development history, mean monthly irrigation requirements, measured stream losses and gains, simulated stream and underflow depletion will also be included. Upon completion of all tributary basin studies, a summary report will be prepared outlining results from each basin study.

BASIN PROJECT PLANS AND COSTS

Individual tributary basin project plans and issues and procedures pertinent to each basin project are presented in Appendix F. Estimates of time and cost to perform each tributary project are listed in Table 9. It is estimated that it would take approximately 85 man months to complete all twenty tributary projects at a 1997 cost of $510,000, including $36,000 and 6 man months for Geographical Information Systems (GIS) costs. These cost are further broken down into the high, medium, and low priority categories described above. The five high priority basin projects could be completed at a cost of $144,000 plus GIS costs (which remain constant regardless of the number of basins completed) for a total of $180,000. The high priority tributary projects could be completed with 30 man months of effort.

Figure 28. Upper Snake River Tributary Basins

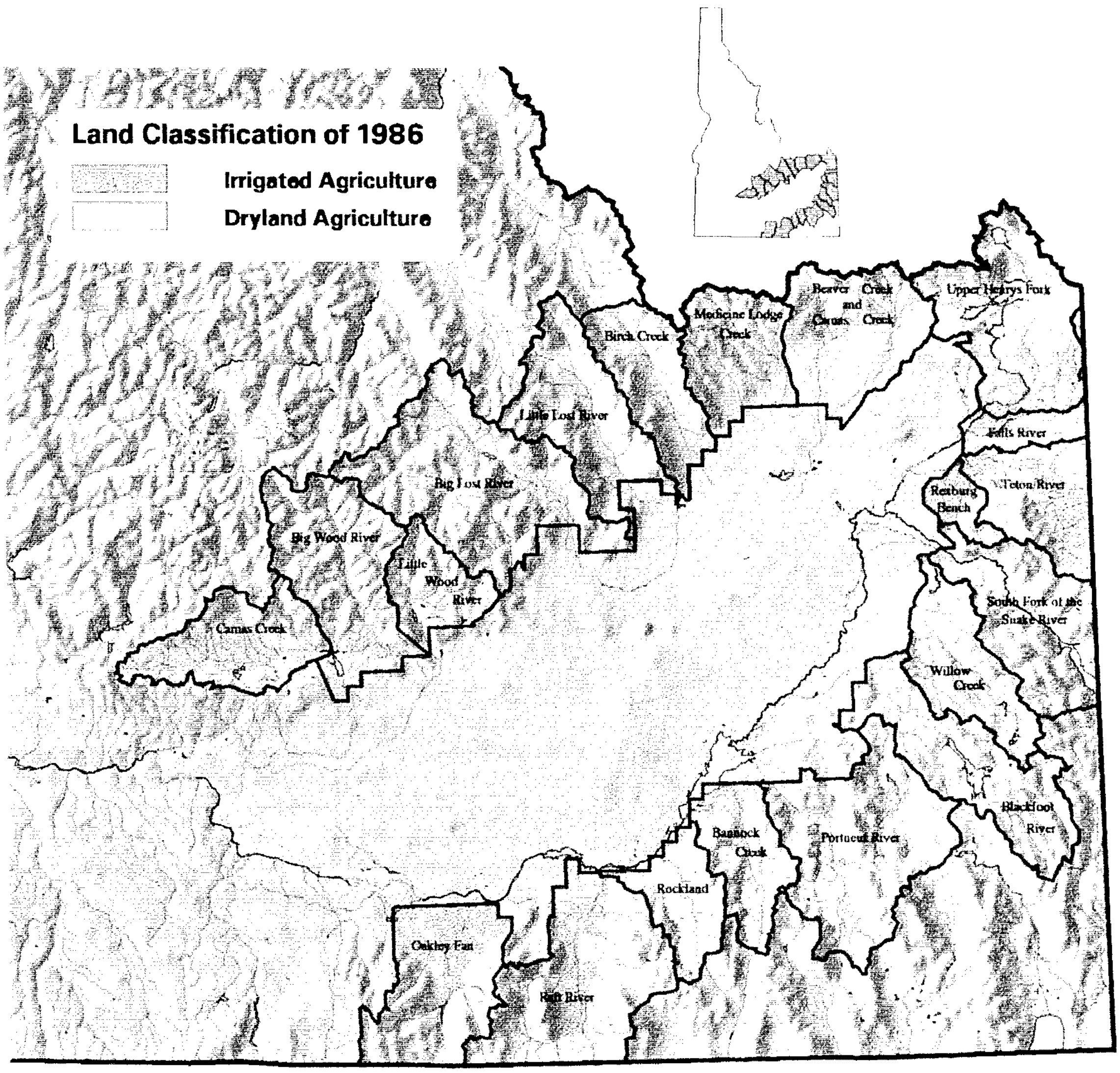


Table 8. Hydrologic Summary of Tributary Basins

Priority	Tributary Basin	Drainage Area (mi^2)	Authorized Ground Water Diversion Rate (cfs)	Total Irrigated Land: 1986 Est. (ac)	Precipitation (1000 ac-ft/yr)	Basin Outflow (1000 ac-ft/yr)	
						Surface Water	Ground Water
Low	Upper Henrys Fork	1,060	10	33,500	1,487 - 1,978	1,088	0
Low	Falls River/Conant Creek	520	13	41,200	971	579	0
Medium	Teton River	890	355	143,200	1,058	597	0
High	Rexburg Bench	165	925	58,500	141 - 174	10	0 - 19
Low	South Fork of Snake River	5,750	24	25,300	10,216	5,022	0
Low	Willow Creek	650	25	5,200	534	100	0 - 29
Low	Blackfoot River	930	18	9,600	987	267	0 - 25
High	Portneuf River	1,290	550	90,700	1,128	202	49 - 63
Medium	Bannock Creek	410	365	45,600	393	28	22 - 30
Low	Rockland	430	58	19,800	295	17	51
High	Raft River	1,510	1,825	104,800	1,248	0	84
High	Oakley Fan	1,630	2,220	171,200	1,347	210	215
Medium	Camas/Beaver Creeks	830	195	14,700	872	37	267
Medium	Medicine Lodge Creek	830	285	9,700	872	41	20 - 30
Low	Birch Creek	600	5	1,400	749	0	57 - 78
Medium	Little Lost River	840	120	11,500	1,147	52	100
High	Big Lost River	1,440	510	69,800	1,206 - 1,551	74	142 - 308
Low	Little Wood River	480	36	26,800	566	124	13 - 24
Medium	Big Wood River/Silver Creek	1,180	345	27,000	1,492	330	38
Medium	Camas Prairie	680	155	110,300	638	128	20

Table 9. Time and Cost Estimates of Proposed Tributary Basin Studies

Tributary Basin	Data Collection		Data Compilation		Model Construction		Model Validation		Model Utilization		Final Report		Basin Total	
	mm	$	mm	$	mm	$	mm	$	mm	$	mm	$	mm	$
Upper Henrys Fork	0.25	1,500	0.75	4,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Falls River/Conant Creek	0.25	1,500	0.25	1,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.0	18,000
Teton River	1.5	9,000	1.5	9,000	1.0	6,000	0.5	3,000	0.5	3,000	1.0	6,000	6.0	36,000
Rexburg Bench	0.5	3,000	1.0	6,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	4.0	24,000
South Fork of Snake River	0.25	1,500	0.25	1,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.0	18,000
Willow Creek	0.25	1,500	0.25	1,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.0	18,000
Blackfoot River	0.25	1,500	0.25	1,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.0	18,000
Portneuf River	1.5	9,000	1.5	9,000	1.0	6,000	0.5	3,000	0.5	3,000	1.0	6,000	6.0	36,000
Bannock Creek	1.0	6,000	1.0	6,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	4.5	27,000
Rockland	0.5	3,000	0.5	3,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Raft River	1.0	6,000	1.5	9,000	1.0	6,000	0.5	3,000	0.5	3,000	1.0	6,000	5.5	33,000
Oakley Fan	0.25	1,500	0.75	4,500	1.0	6,000	0.5	3,000	0.5	3,000	1.0	6,000	4.0	24,000
Camas/Beaver Creeks	0.5	3,000	1.0	6,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	4.0	24,000
Medicine Lodge Creek	1.0	6,000	1.0	6,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	4.5	27,000
Birch Creek	0.25	1,500	0.25	1,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.0	18,000
Little Lost River	0.25	1,500	0.75	4,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Big Lost River	0.5	3,000	1.0	6,000	1.0	6,000	0.5	3,000	0.5	3,000	1.0	6,000	4.5	27,000
Little Wood River	0.5	3,000	0.5	3,000	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Big Wood River/Silver Creek	0.25	1,500	0.75	4,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Camas Prairie	0.25	1,500	0.75	4,500	0.5	3,000	0.5	3,000	0.5	3,000	1.0	6,000	3.5	21,000
Geographic Information System work													6.0	36,000
All Twenty Tributary Basin Studies													**85.0**	**510,000**

mm = man-month

ESPA MANAGED RECHARGE

In an effort to retain more surface runoff from the Snake River and its tributaries in the Upper Snake River Basin and to increase ESPA water table levels and year-round spring discharge to surface streams, several plans and demonstration projects for recharging the aquifer have been developed over the past 25 years. The technical committee included a study element to prepare a plan of study for an "artificial" recharge project. The committee viewed additional recharge as potentially beneficial by increasing water supplies available in the Upper Snake River Basin and providing a tool for a conjunctive management plan. This section explores the potential opportunities for "managed" recharge which can be defined as "the addition of water to a confined or unconfined aquifer in an effective, efficient and controlled manner for the sole purpose of achieving defined and predictable responses in the aquifer as measured by ground water elevations and/or spring discharges."

Successful managed recharge of the ESPA is dependent on four factors: 1) the identification of suitable recharge sites; 2) adequate delivery systems to convey the water to the recharge sites; 3) the availability of water of suitable quality from surface sources; and 4) institutional approvals.

RECHARGE SITES AND DELIVERY SYSTEMS

To address the issue of potential recharge sites and adequate delivery systems, the University of Idaho was contracted to investigate the feasibility of using existing canals to facilitate additional recharge beyond the incidental recharge which exists as a result of normal irrigation practices. Since 1994 many canals in Water District 1 have begun to divert water above their normal irrigation needs for aquifer recharge as a result of legislation that same year which funded purchase of water from the water bank and provided funding for a portion of the conveyance costs. The identification of new recharge sites, which would require design and construction costs, was considered beyond the scope of this study.

Detailed results of the University of Idaho study are presented in a separate report (Sullivan, et al, 1996). Recharge capacities of existing (or easily modified) systems in the Upper Snake were defined in the recharge study (Table 10). Capacities were grouped according to locations in three general areas: 1) Egin, 2) Blackfoot, and 3) Milner. These capacities take into account both suitable sites and adequate delivery systems, but do not reflect adequate supply or institutional approvals.

Table 10. Canal System Capacity for Additional Managed Recharge Diversions

Recharge Area	cfs													kaf
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Yr	Yr
Egin	617	474	326	310	457	697	624	406	382	391	464	655	492	356
Blackfoot	853	624	20	0	275	570	1037	351	74	44	304	437	381	276
Milner	832	882	0	0	0	516	682	547	197	124	114	482	366	265

AVAILABILITY OF SURFACE WATER FOR RECHARGE

Existing canal system capacity values (Table 10) were compared with surplus natural flow and flood release availability in Water District 1 using the IDWR 1928-1992 monthly surface water planning model base study. The IDWR base study (Robertson, et al, 1989) represents flows and reservoir contents over the 65 year period under present conditions of development and operational rules. The recharge capacities at the three areas were compared to the base study surplus flows at the same locations to identify divertable amounts. Surplus flows are defined as those which would have spilled past Milner Dam and out of Water District 1 had they not been diverted and for which no other prior right would demand the water for a consumptive use. An assessment of the quality of these surplus flows was beyond the scope of this study.

There are a number of constraints that may affect the availability of water for recharge. These include hydropower water rights, Snake River water quality concerns, federal and tribal reserved water rights in the lower Snake River, and necessary flow regimes for endangered or threatened species. An evaluation of these constraints on the availability of water for recharge was beyond the scope of this study, but should be addressed in future studies. For the purpose of this study, a worst case assumption regarding the effect of hydropower water rights was used to illustrate the magnitude of potential effects these constraints could have on the amount of water available for recharge.

From the IDWR surface water base study, the average annual flow passing the Milner gaging station on the Snake River is approximately 2.3 million acre-feet. Of this amount, it was estimated that approximately 2.0 million acre-feet is surplus flow if hydropower rights are ignored. The monthly comparison of surplus flow with recharge capability yielded an annual average of 346,000 acre-feet with the potential to be diverted for recharge (Scenario A).

There are several locations on the Snake River where hydropower constraints may limit diversions to recharge. To assess the potential and extent of hydropower constraints to restrict recharge, a review was made of all major hydropower rights on the Snake River above the King Hill gaging station. The review identified major power rights not specifically subordinated to recharge and having rates large enough to impact recharge.

A second comparison (Scenario B) of flow availability relative to recharge capability was made to illustrate the magnitude of the potential impact of hydropower rights. Hydropower rights at three locations which may have an effect were added as a constraint on recharge water availability as follows:

St. Anthony	800 cfs
American Falls	9,000 cfs
Lower Salmon Falls	17,250 cfs

Results of this comparison yielded only 43,000 acre-feet average annual divertable flow to recharge. This example demonstrates that administration of hydropower rights can have a significant effect on managed recharge projects.

Table 11 characterizes the average annual flow of the Snake River at Milner from the IDWR surface water model base study and the recharge study results. Scenario A assumes that all power rights would be subordinated to managed recharge diversions, and Scenario B assumes that the power rights at St. Anthony, American Falls, and Lower Salmon Falls would be met before recharge could occur.

Table 11. 1928-1992 Average Annual Discharge at Milner and Divertable Recharge Using Existing Canal Capacities

	(acre-feet)	(cfs)
Base Study	2,312,000	3190
Surplus Flow	1,987,000	2740
Divertable Recharge - Scenario A	346,000	480
Divertable Recharge - Scenario B	3,000	60

Table 11 illustrates that canal capacities limit the ability to divert surplus flow (1,987,000 acre-feet) to less than twenty percent (Scenario A). Recognition of hydropower rights (Scenario B) further limits the ability to recharge with surplus flow to about two percent of the supply.

These scenarios are examples of possible water supplies available for managed recharge. Actual constraints posed by hydropower are beyond the scope of this study and need to be investigated further. Available surface water may include additional supplies of storage water from unallocated, purchased, or rented sources. Use of storage water would increase available water supplies if used in conjunction with surplus flow, but any new use of stored water would reduce surplus flow passing through Water District 1 as a result of creating additional storage space to capture the flow. At the present time the amount of storage water available over the long term is difficult, if not impossible, to predict in view of the multitude of competing uses for stored water. It should also be noted, however, that the following ground water simulation studies illustrating the effects of recharge are dependent on volume and location of recharge but not on whether the source is surplus flow or storage water. Results of the ground water simulations using storage would be identical to those using surplus flows assuming volumes were of the same magnitude.

AQUIFER RESPONSE

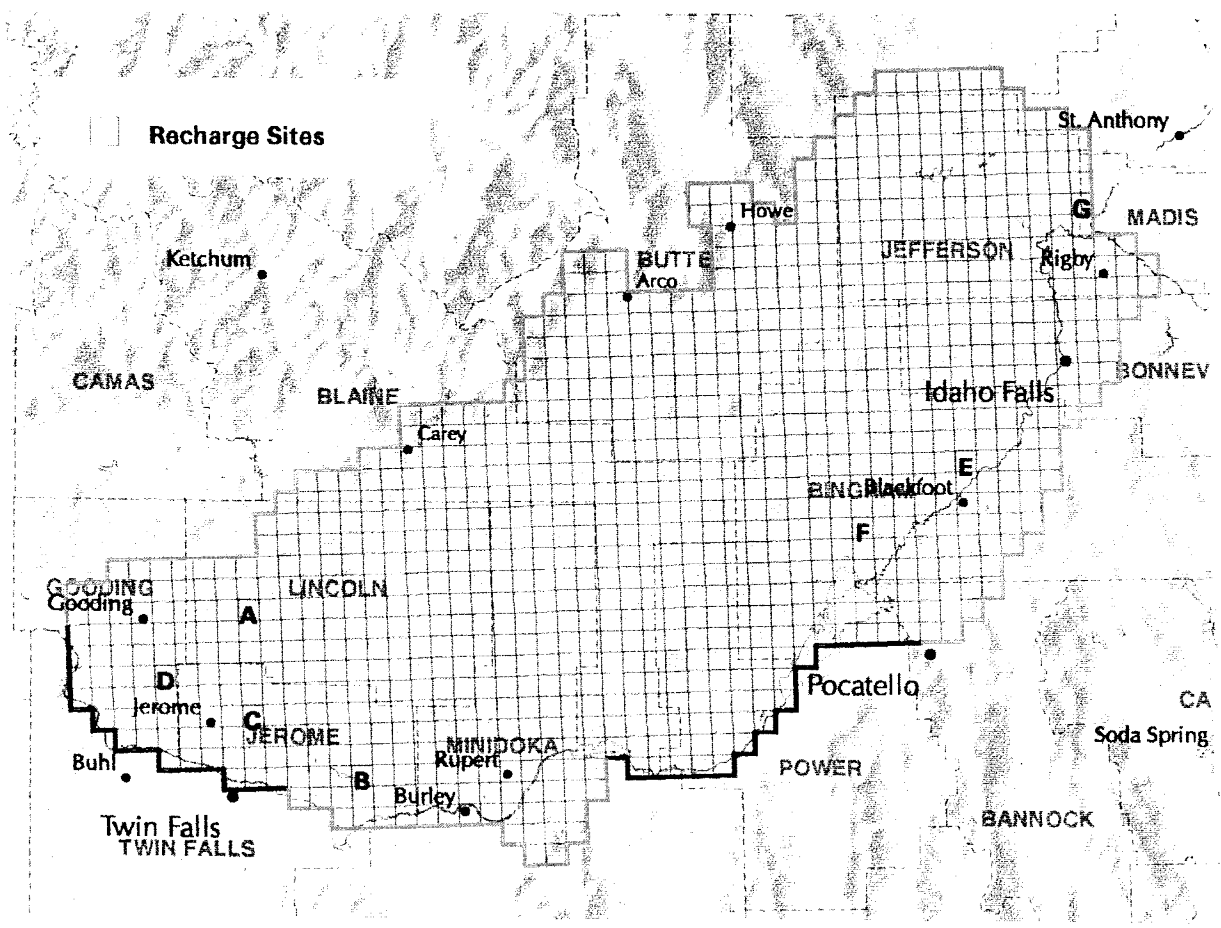
The water available for recharge from each of the above scenarios was added to the appropriate nodes in the ground water model to assess the effect of recharge on spring outflows and ground water levels over the ESPA. Seven locations were identified (Figure 29) overlying the aquifer where recharge was added based on the University of Idaho report on recharge capability of existing canals. These locations are not specific points where recharge would occur, but represent multiple sites in the general area.

Two options were modeled for each scenario. For option 1 of each scenario, the location of the recharge water was kept as low in the Upper Snake system as possible. Available water was diverted first at Milner, then Blackfoot, and if additional water was still available, finally at the Egin location. In option 2, the location of the recharge water was kept as high in the system as possible by diverting first at Egin, then Blackfoot, and finally at Milner. This was done to assess the effect on spring flows and water table elevations relative to the general location of recharge.

Crop and land use data, computation of recharge on the irrigated and non-irrigated acres, computation of irrigation diversions, climate data and crop distribution data, tributary valley underflow estimates, and river reach gains and losses were all the same as described for the base study. The boundary configuration was identical to that used in the base study. Leakage computed by the HFA ground water model for the base study was adjusted based on computed changes in head in the ESPA model underlying the HFA for each timestep (Appendix D). The model simulation used transmissivity and storage coefficient values from the initial calibration. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section).

The combined recharge source term for the managed recharge studies is the average net recharge to the ESPA at the present level of development increased only by the amount of new recharge. This was done by adding injection wells at specific nodes (Figure 29) on an average annual time schedule. These inputs, for options 1 and 2 of scenarios A and B, are summarized by node and timestep in Tables 12 through 15. Estimated head values and outflows for the recharge simulations were determined by repeatedly running the 24 timestep sequence of average annual recharge source terms.

Figure 29. Managed Recharge Sites on the Eastern Snake Plain Aquifer



5K Model Cell Size (Hydraulically Connected) (No Flow)

Table 12. Average Potential ESPA Managed Recharge Using Existing Systems and Surplus Snake River Flows

Scenario A, Option 1: Assuming Recharge Not Subject to Hydropower Constraints - Recharge Sequence = Milner/Blackfoot/Egin

(kaf)

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
A	5.8	13.3				12.2	16.8	12.5				0.9	61.5
B	1.1	10				2.5	4.2	2.5	1.8	0.3	0.3	0.2	22.9
C	0.7	8.2				2.1	3.4	2.1	1.5	0.2	0.2	0.1	18.5
D	1.1	10				2.5	4.2	2.5	1.8	0.1	0.1	0.1	22.4
E	0.4	2.3	0.7			0.6	5.5	1.6	1.1	0.2	0.2	0.1	12.7
F	7.7	17.3			7.5	14.7	32.5	10.8	0.8		1	1.1	93.4
G	5.3	12	11.8	10.3	9.1	15.1	20.1	17.2	9.5	1.8	1.8	0.8	114.8
Total	22.1	73.1	12.5	10.3	16.6	49.7	86.7	49.2	16.5	2.6	3.6	3.3	346.2

Table 13. Average Potential ESPA Managed Recharge Using Existing Systems and Surplus Snake River Flows

Scenario A, Option 2: Assuming Recharge Not Subject to Hydropower Constraints - Recharge Sequence = Egin/Blackfoot/Milner

(kaf)

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
A	5.2	28.2				11.5	15.7	12.1				0.2	72.9
B	1	4.7				2.3	3.9	2.4	1.7	0.2	0.2	0.1	16.5
C	0.7	3.9				2.1	3.2	2	1.4	0.1			13.4
D	1	4.7				2.3	3.9	2.4	1.7	0.2	0.2	0.1	16.5
E	0.4	1.9	0.7			0.4	5.1	1.6	1.1	0.2	0.2	0.1	11.7
F	7.3	14.4			5	12.2	30.6	10.9	0.7		1	1	83.1
G	6.6	15.4	11.8	10.3	11.6	18.7	24.3	18	9.8	1.8	1.9	1.9	132.1
Total	22.2	73.2	12.5	10.3	16.6	49.5	86.7	49.4	16.4	2.5	3.5	3.4	346.2

Table 14. Average Potential ESPA Managed Recharge Using Existing Systems and Surplus Snake River Flows

Scenario B, Option 1: Assuming Recharge Subject to Hydropower Constraints - Recharge Sequence = Milner/Blackfoot/Egin

(kaf)

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
A		1.2				0.6	5.1	2.1					9
B		0.2				0.2	1.3	0.5	0.5				2.7
C		0.1				0.1	1	0.2	0.3				1.7
D		0.2				0.1	1.3	0.5	0.1				2.2
E		0.1	0.1			0	1.6	0.2	0.2				2.2
F		0.5				1.1	9.4	1.4	0.1				12.5
G		0.1	0.1	2.2		1.3	5.5	1.9	1.3				12.4
Total		2.4	0.2	2.2	0	3.4	25.2	6.8	2.5	0	0	0	42.7

Table 15. Average Potential ESPA Managed Recharge Using Existing Systems and Surplus Snake River Flows

Scenario B, Option 2: Assuming Recharge Subject to Hydropower Constraints - Recharge Sequence = Egin/Blackfoot/Milner

(kaf)

Site	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
A		0.3				0.6	3.6	1.3					5.8
B		0.1				0.2	0.9	0.3	0.3				1.8
C							0.7	0.2	0.1				1
D		0.1				0.2	0.9	0.3	0.3				1.8
E		0.1					1.6	0.2	0.2				2.1
F		0.9				1.1	9.5	1.4	0.1				13
G		1	0.1	2.2		1.3	8	3	1.6				17.2
Total	0	2.5	0.1	2.2	0	3.4	25.2	6.7	2.6	0	0	0	42.7

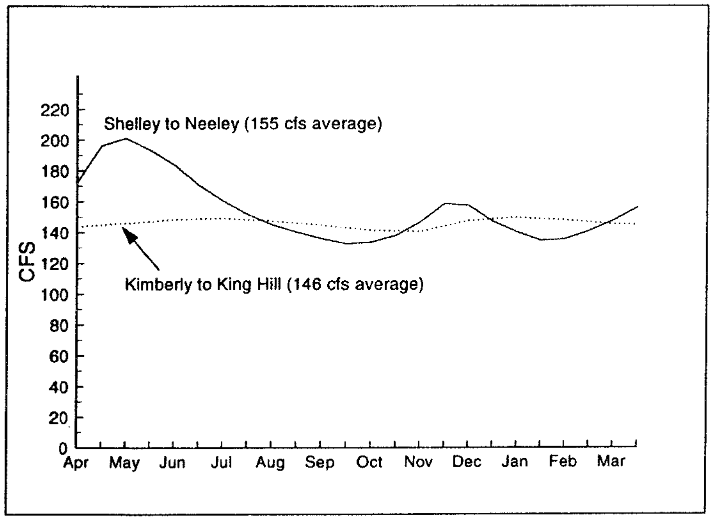


Figure 30. ESPA Managed Recharge Study Scenario A option 1, Difference in Spring Discharge from Base after 25 Years

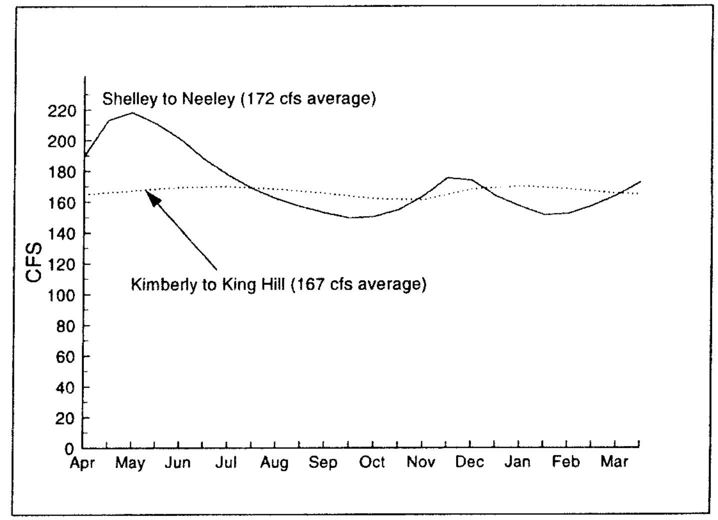


Figure 31. ESPA Managed Recharge Study Scenario A option 1, Difference in Spring Discharge from Base after 100 Years

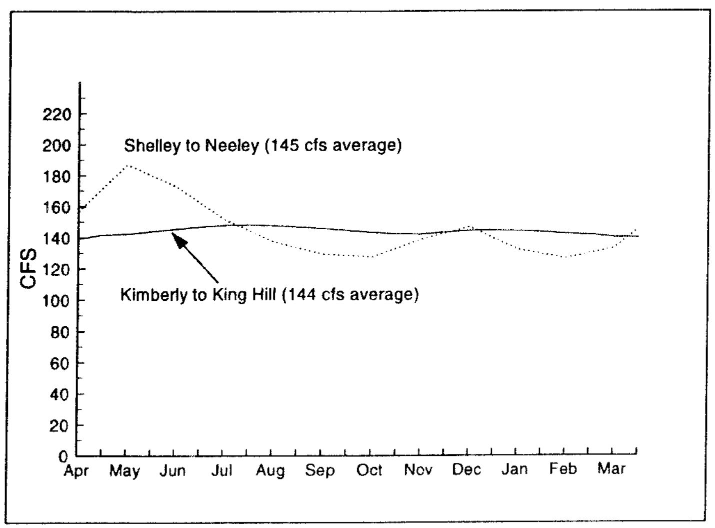


Figure 32. ESPA Managed Recharge Study Scenario A option 2, Difference in Spring Discharge from Base after 25 years

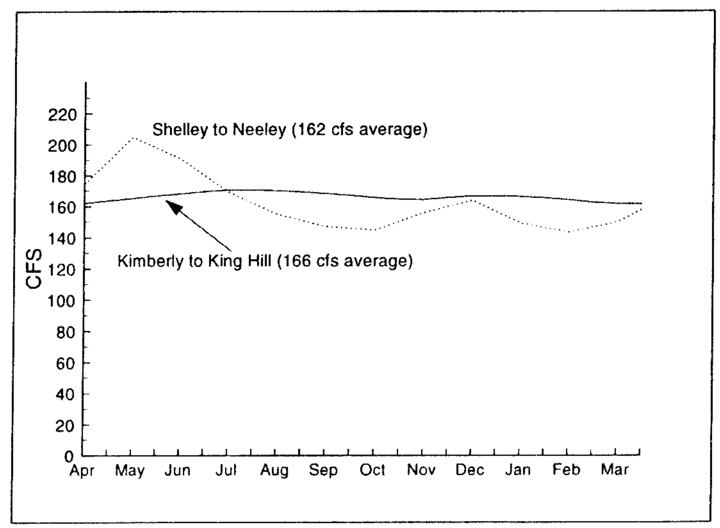


Figure 33. ESPA Managed Recharge Study Scenario A option 2, Difference in Spring Discharge from Base after 100 Years

After simulation of a one hundred year period, annual change in aquifer storage for each of the scenario A studies was approximately 11,000 acre-feet, which is indicative of equilibrium conditions. The speed at which the aquifer responds to the increase in recharge is indicated by the rate of the change in annual aquifer change in storage. The annual aquifer change in storage after year 25 for each of the scenario A studies was approximately 38,000 acre-feet.

The scenario A, option 1 study added an annual average of 346,000 acre-feet of recharge water maximized over the western ESPA (Milner/Blackfoot/Egin). After 25 years of simulation using the recharge values for scenario A, option 1, change in aquifer discharge for the Shelley to Neeley and Kimberly to King Hill reaches of the Snake River averaged 155 cfs and 146 cfs, respectively (Figure 30), and at equilibrium (100 years) averaged 172 cfs and 167 cfs, respectively (Figure 31). Leakage from the HFA to the ESPA was reduced by approximately 122 cfs and 126 cfs after 25 and 100 years, respectively.

Scenario A, option 2 is identical to Option 1 except that recharge is maximized in the eastern portion of the ESPA (Egin/Blackfoot/Milner). After 25 years of simulation, change in computed aquifer discharge for the Shelley to Neeley and Kimberly to King Hill reaches of the Snake River averaged 145 and 144 cfs, respectively (Figure 32), and after 100 years averaged 162 cfs and 166 cfs, respectively (Figure 33). Leakage from the HFA to the ESPA was reduced by approximately 138 cfs and 142 cfs after 25 and 100 years, respectively.

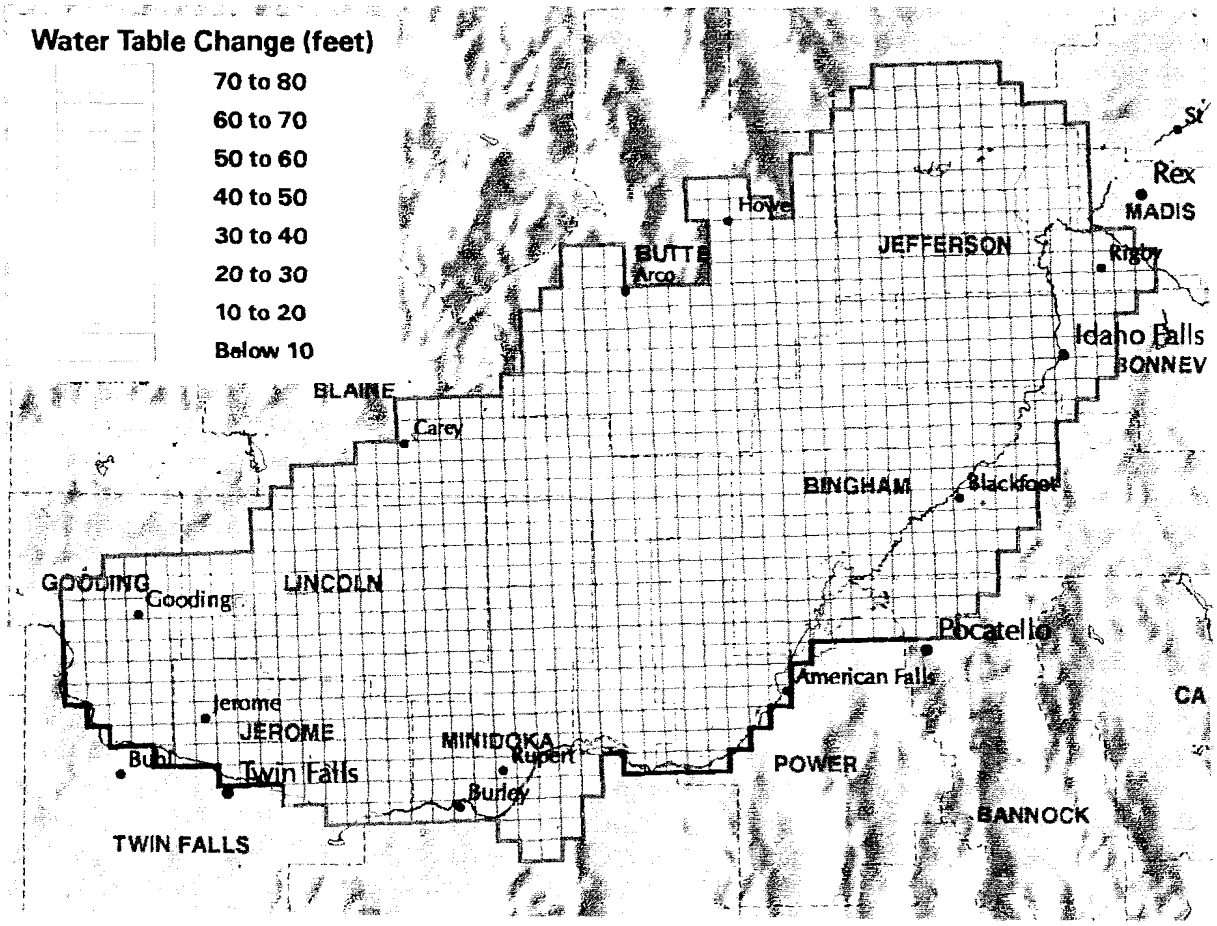
A comparison of options 1 and 2 shows that moving recharge to the eastern portion of the ESPA results in less leakage from the HFA. The reduced leakage translates into greater surface flow in the Henrys Fork and Rigby Fan area with an equivalent reduction in gains to the Snake River from Shelley to Neeley and Kimberly to King Hill.

Figure 34 shows the change (from base conditions) in ground water elevations over the ESPA after 25 years of simulation for scenario A, option 1. Increases in water table elevations range from less than 10 feet in the central ESPA to more than 70 feet in areas close to recharge sites. Similar increases in ground water elevations occurred for scenario A, option 2. It should be noted that although water table changes in elevation would be greater in the proximity of recharge sites, results shown here are influenced by the transmissivity of the particular node chosen for injection and may not be representative of the actual area of recharge.

Recharge for scenario B is limited to an average annual recharge of 43,000 acre-feet due to hydropower constraints. Again, scenario B, options 1 and 2 are identical except that recharge is maximized in the western portion of the ESPA (Egin/ Blackfoot/Milner) for option 1 and the eastern portion (Milner/Blackfoot/Egin) in option 2. Scenario B increases in water table elevations ranged from less than 0.5 foot in the central ESPA to less than 3 feet in areas close to recharge sites. After 25 and 100 years of simulation, change in computed aquifer discharge for the Shelley to Neeley and Kimberly to King Hill reaches of the Snake River were each less than 25 cfs for both options, as was the leakage change from the HFA to the ESPA. Therefore, it can be concluded that the magnitude of managed recharge provided by Scenario B is not significant.

Table 16 summarizes the four managed recharge studies listing changes in Snake River gains and changes in Henrys Fork gains due to change in HFA leakage.

Figure 34. Change in Water Table Elevation Aafter 25 years for Managed Recharge Study Scenario A, Option 1



5K Model Cell Size (Hydraulically Connected) (No Flow)

Table 16. Summary of Effects on ESPA for Managed Recharge Studies

Study	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)
	After 25th Year of Simulation			After 100th Year of Simulation		
Scenario A, Option 1	155	146	122	172	167	126
Scenario A, Option 2	145	144	138	162	162	142
Scenario B, Option 1	20	18	13	22	21	14
Scenario B, Option 2	22	12	18	24	14	19

SUMMARY AND CONCLUSIONS

A review of current data showed that there is no justification for redefining the 1986 trust/non-trust ground water line. Ground water flow lines representing spring and fall 1993 conditions showed only minor differences from those used in 1986.

The existing ground water flow model developed by UI and IDWR was used to study the ESPA under various conditions and stresses of development. Although the IDWR/UI ground water model had previously been calibrated, it was recalibrated using more recent and comprehensive data. Recalibration of the IDWR/UI ground water model required multiple trial simulations during which transmissivity and storage coefficient parameters were adjusted to produce a match of historic aquifer discharge and water table elevation values. Final calibration was achieved when simulations using a set of reasonable transmissivities and storage coefficients resulted in an average water table elevation deviation of 3.7 feet and an average difference in aquifer discharge of 250 cfs, as compared to historical values.

Aquifer discharge and water levels on the ESPA have not reached equilibrium and are still responding to historical development. In 1992, over the modeled area of the ESPA approximately 611,000 acres were irrigated from surface water sources, and 818,000 acres were irrigated from ground water sources. By holding net recharge reflecting this level of irrigation constant over many years, a model run was made to simulate equilibrium conditions for a "base study" from which to measure the impact of each "what if" study. At equilibrium, the base study simulation produced an annual average aquifer discharge in the Shelley to Neeley and Kimberly to King Hill reaches of 2665 and 5526 cfs, respectively.

The "what if" model studies compute aquifer discharge values for the Shelley to Neeley reach and the Kimberly to King Hill reach of the Snake River, and the effect on gains to the Henrys Fork by running repeated annual cycles for a single condition. The differences in simulated aquifer discharge from base conditions for each "what if" study are shown in Table 17 after the 25th year and at equilibrium conditions (after 100 years). At 25 years, the change in discharges range from 70 to 90 percent of the equilibrium values. For all of these model runs, changes in net recharge, whether positive or negative, at first have a greater relative impact on aquifer storage, either adding or removing water from the aquifer directly. As equilibrium is approached, changes in storage become smaller while the total change in aquifer discharge to streams and springs becomes greater.

To evaluate the effect of existing irrigation pumping on ESPA discharge and water levels ("no ground water" study), the model was run with all ground water use deleted with the exception of use in the vicinity of the Fort Hall Indian Reservation. At equilibrium, the aquifer discharge for the Shelley to Neeley reach increased by 848 cfs and the Kimberly to King Hill reach increased 620 cfs. It is assumed that the aquifer discharge values after 25 years, the average age of existing ground water development, is representative of the effect of pumping on present aquifer discharge. The aquifer discharge after 25 years for the Kimberly to Neeley reach shows a 675 cfs increase, and the Kimberly to King Hill values increased by 500 cfs. Therefore, 675 cfs of the 848 cfs decrease (80 percent) in the Shelley to Neeley reach has already occurred and 500 cfs of the 620 cfs (80 percent) in the Kimberly to Neeley reach has also occurred.

Table 17. Summary of Effects on ESPA for Upper Snake River Basin Studies

Study	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Differenc e in Gain to Henry's Fork from Base Study Due to Change in HFA Leakage (cfs)	Differenc e in Compute d Discharge from Base Study Shelley to Neeley (cfs)	Differenc e in Compute d Discharge from Base Study Kimberly to King Hill (cfs)	Differenc e in Gain to Henry's Fork from Base Study Due to Change in HFA Leakage (cfs)
	After 25th Year of Simulation			After 100th Year of Simulation		
No Groundwater	675	499	120	848	620	174
1965-76 Surface Diversions	287	371	48	327	423	62
5% Reduction Surface Diversions	-142	-132	-22	-158	-152	-25
10% Reduction Surface Diversions	-283	-264	-44	-315	-303	-50
15% Reduction Surface Diversions	-424	-396	-64	-472	-455	-75
20% Reduction Surface Diversions	-565	-527	-87	-629	-607	-99
Recharge Scenario A, Option 1	155	146	122	172	167	126
Recharge Scenario A, Option 2	145	144	138	162	162	142
Recharge Scenario B, Option 1	20	18	13	22	21	14
Recharge Scenario B, Option 2	22	12	18	24	14	19

The estimated change from base conditions in Henrys Fork gains due to changes in HFA leakage directly affects natural flow in the study area. To estimate the total change in natural flow in Water District 1, the change in the Henrys Fork gain should be added to the computed change in aquifer discharge in the Shelley to Neeley reach of the Snake River. For example, under the "no ground water" study, the total change in natural flow in Water District 1 after the 25^{th} year would be 675 cfs plus 120 cfs or about 895 cfs. Results of the "no ground water" study are shown graphically in Figure 35.

The water right accounting system used in Water District 1 was used to allocate the impact of flow reductions (decreases in aquifer discharge and thus, natural river flow) among water right holders. The actual accounting for 1993, an average runoff year, and 1992, a dry year, was rerun using the after 25th year impact on natural flow of 895 cfs. The 1993 run resulted in an increase in system reservoir storage of 51,000 acre-feet if ground water withdrawals for irrigation had not occurred. Additionally, the North Side and the Twin Falls Canal Companies would have used 43,000 acre-feet and 53,000 acre-feet less storage, respectively. Other users accounted for another 67,000 acre-feet in storage use reduction. In the 1992 run, the numbers are larger, totaling almost 300,000 acre-feet.

An estimate of the magnitude of the impact on the ESPA from recent reductions in recharge from surface irrigation was made by changing surface irrigation recharge to 1965-1976 levels. Although not directly comparable or additive, results of the model run indicate that surface diversion reduction impact is less than the impact due to ground water pumping and may be on the order of 50 percent of the pumping effect. Relative to ground water pumping, the impact of surface irrigation reduction on natural flows in Water District 1 is less, with less than 50 percent of the reduction occurring above Milner as compared to more than 60 percent in the ground water study. Results of the "1965-1976 diversions" study are shown graphically in Figure 36.

The 5, 10, 15 and 20 percent additional reduction in surface irrigation studies show that further increases in irrigation efficiency could have a major impact on future aquifer discharges. An increase in surface irrigation efficiency of 10 percent could further decrease aquifer discharge on the order of 600 cfs.

No model simulations were made to estimate the effects of increases in irrigated lands over the ESPA. The potential for the development of new irrigation over the ESPA was found by IWRB planning studies to be very limited.

There are twenty basins tributary to the ESPA where studies are necessary to evaluate the impact on the ESPA of development in those tributaries. These studies could be completed at a cost of $546,000 and 91 man-months of effort. There are five basins which have a high priority for study completion based on a greater level of ground water development. Study costs for these five basins are a total of $180,000 and 30 man-months of effort.

Managed recharge has been identified as one option to raise water levels and increase aquifer discharge to the Snake River. IDWR contracted with the University of Idaho, Water Resources Research Institute to identify the best available sites where existing canals could be used in a managed recharge program. While site characteristics suggest there are significant potential recharge sites, the amount of water available establishes the upper limit for recharge capability. A comparison of the diversion capability of existing canals with the availability of surplus natural flow and flood releases show that on the average from 43,000 to 346,000 acre-feet per year could be diverted for recharge, depending on the effect of existing hydropower constraints.

Recharge study results indicate that using existing sites and surplus flows for recharge result in offsetting only about 30 percent of the effects of ground water pumping. However, a seven percent change in surface diversion efficiency results in an equivalent change in recharge. Furthermore, it was shown that very little flexibility exists in achieving specific recharge objectives with existing canals because of the limited capacity of those canals. The effect of using existing facilities to concentrate the recharge in the eastern ESPA (upper system) and the western ESPA (lower system) was analyzed. Studies optimizing upper and lower system recharge produced very little difference in effect on aquifer discharge or water table elevation for both location and timing. Managed recharge capability could be increased significantly by acquisition of storage water and/or the development of new sites not dependent on existing facilities. Results show that hydropower constraints must be addressed for significant recharge to occur. Results of the managed recharge studies are shown graphically in Figure 37.

The simulations run for this study do not model actual sequential annual changes in aquifer discharge or ground water levels, but do provide valuable information needed to evaluate and address a number of issues. Model runs have shown the general magnitude of *average* impact of recent and possible future changes effecting the ESPA. Year to year impacts may be larger or smaller depending on corresponding year to year changes in net recharge. However, any change in net recharge to the aquifer will result in an almost equal change in discharge from the aquifer at equilibrium, although the dampening effect of the aquifer may delay this effect for many years.

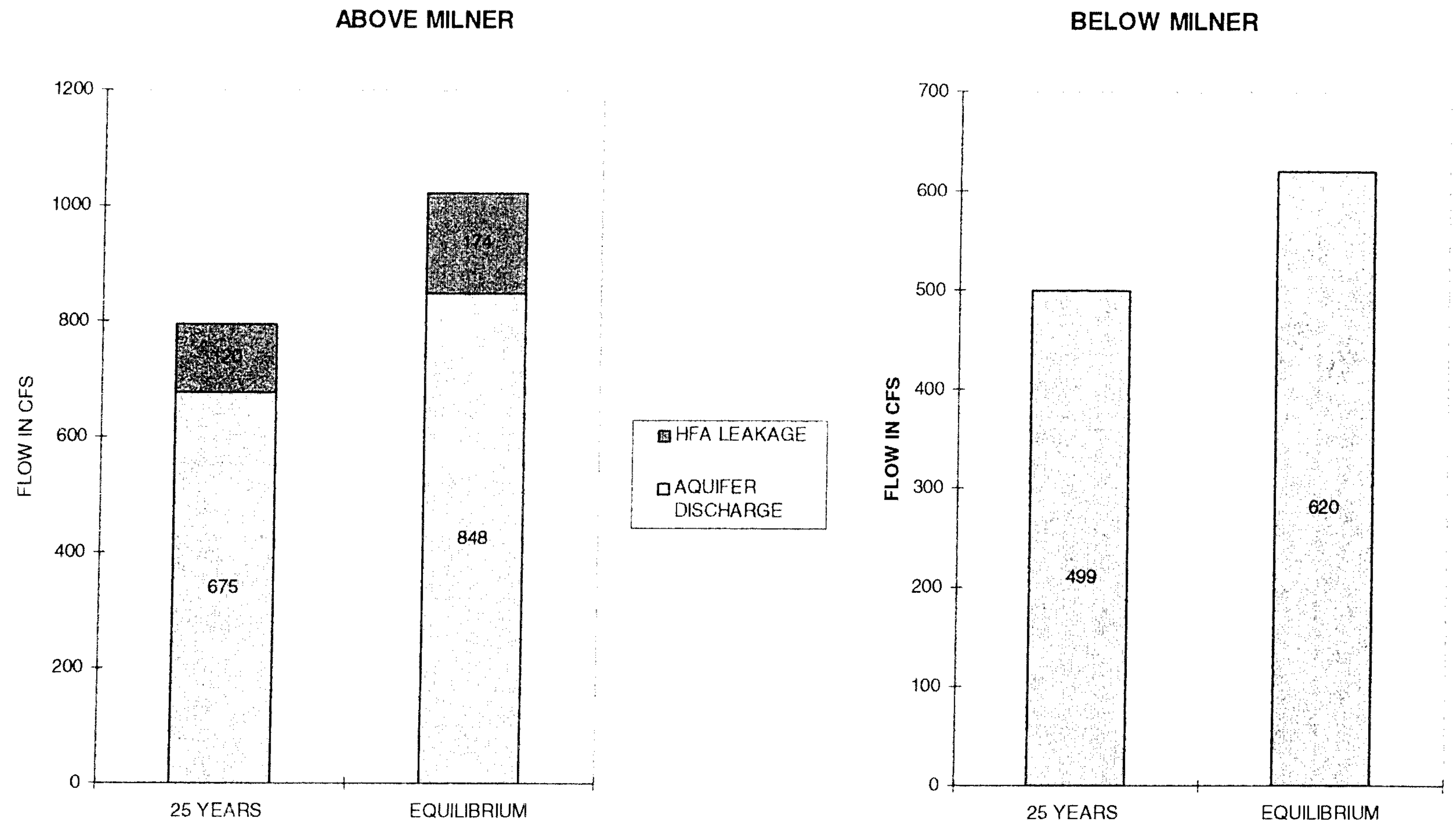


Figure 35. Change in Simulated Reach Gains for "No Ground Water" Study

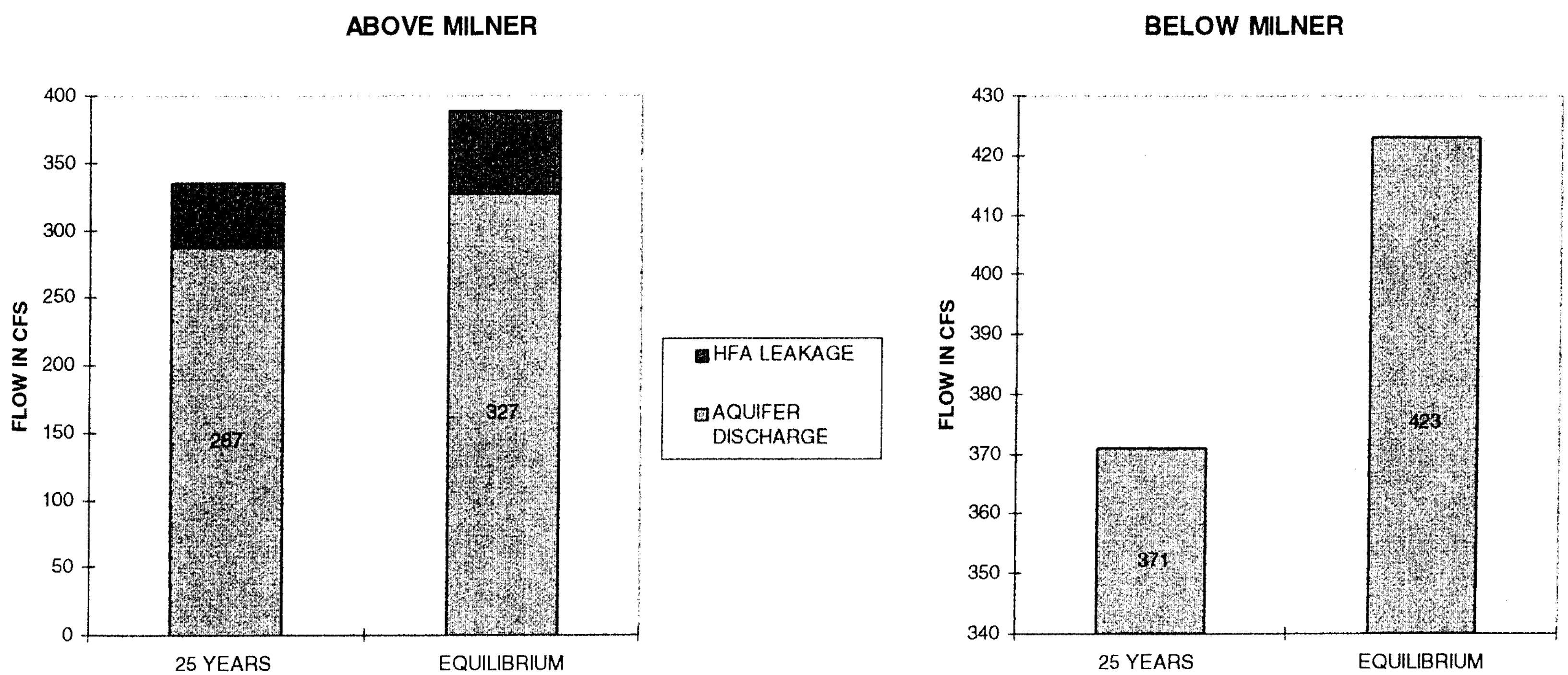


Figure 36. Change in Simulated Reach Gains for "1965-1976 Surface Diversions" Study

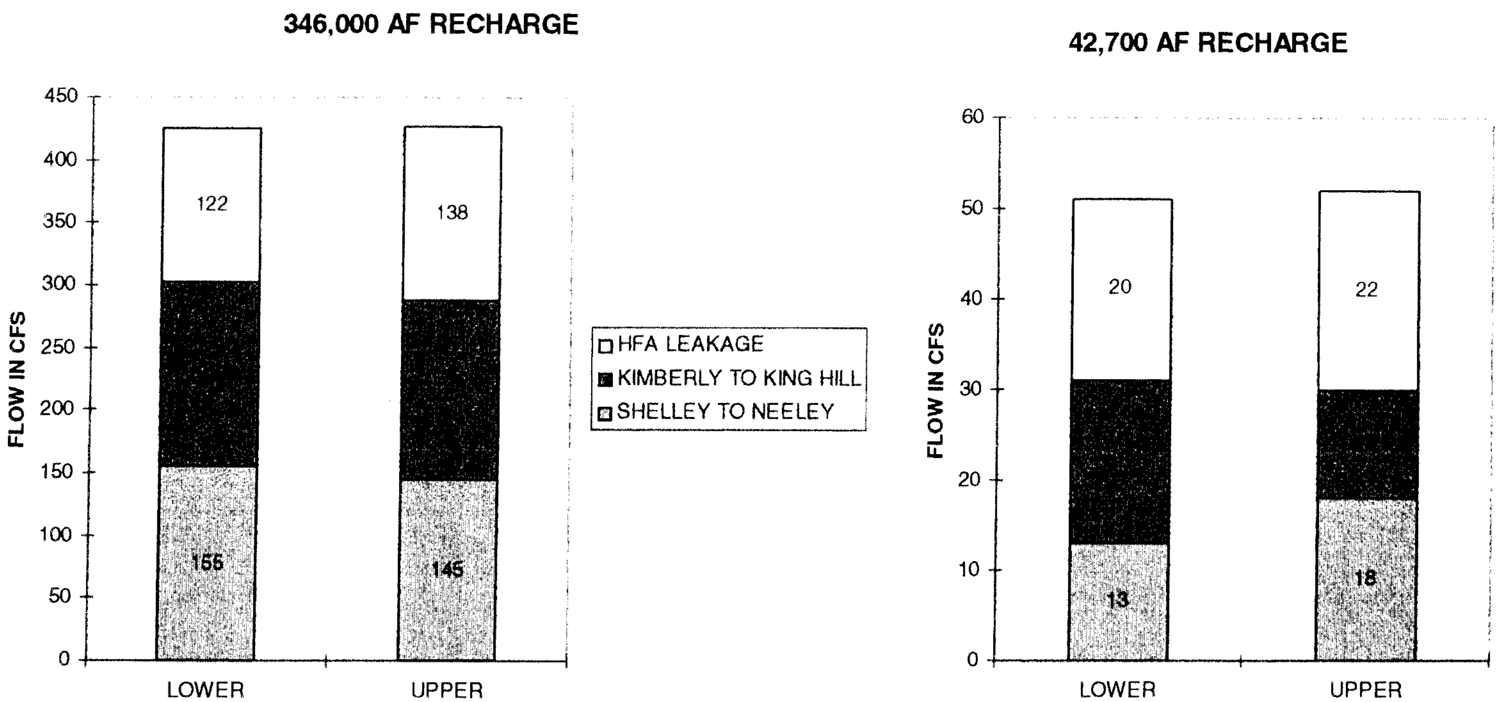


Figure 37. Change in Simulated Reach Gains after 25 Years for Managed Recharge Studies

EPILOGUE

Where We Go From Here - A Framework for Planning Mitigation

by Karl J. Dreher
Director, Idaho Department of Water Resources

This report, which documents the Upper Snake River Basin Study, culminates more than three years of work effort by staff of the Idaho Department of Water Resources, and technical review by the Idaho Technical Committee on Hydrology, to estimate the effects of ground water withdrawals from the Eastern Snake Plain Aquifer and various changes in water use on flows in the Snake River and tributary springs. The data and analytical model that were developed provide the best information available to date on the interrelationships between ground water and surface water in the Upper Snake River Basin.

Some who read this report will claim that the results from this effort can be directly used to quantify impacts and injury to holders of senior surface water rights from ground water diversions under rights having junior priorities. Others will claim that the modeling assumptions, the relatively coarse refinement of the analytical model, and the limited data, render the results unsuitable for quantifying the impacts with sufficient certainty to substantiate any injury. In my judgement, the truth falls between these bounds.

Idaho's constitutional and statutory implementation of the prior appropriation doctrine requires that water rights of senior appropriators be protected. However, that protection does not extend to the point of denying junior appropriators use of water that is beyond the amount necessary to meet the rights of senior appropriators. So, how can the rights of senior surface water appropriators be protected from injury by junior ground water appropriators? I believe this protection can be provided through adequate management of the resource, which includes regulating water diversions and the implementation of mitigation plans.

Adequate management requires knowledge of the resource and collaborative efforts between resource users and resource managers. In terms of knowledge, the Upper Snake River Basin Study described in this report provides a much improved level of knowledge compared with what existed prior to the study. However, even though all of the study elements of the study plan developed for the Upper Snake River Basin Study were completed, "gaps" exist between the knowledge gained from the study and the level of knowledge needed to formulate appropriate mitigation plans. For example, one of the conclusions from the study concerning recharge is that even if all existing canal facilities are used to convey water for recharge when available, the amount of recharge will not be sufficient to restore ground water levels and spring discharges to desirable levels. The study plan did not include a task to evaluate any potential recharge sites that could be developed with new conveyance facilities that could more closely achieve desirable ground water levels and spring discharges. Consequently, this task remains to be completed.

Another area not fully addressed by the plan of study completed by the Upper Snake River Basin Study is the question of injury to holders of senior surface water rights from ground water diversions under rights having junior priorities. One of the principal elements of the study was the estimation of the effects from ground water uses on water availability to the North Side and Twin Falls Canal Companies. This was accomplished by taking the estimated effects of ground water withdrawals on gains to the Snake River and inputting those effects into the accounting system used by Water District 1 to account for use of natural river flow and storage water. This approach provided an estimate of the magnitude of the impact from junior priority ground water diversions on water availability for senior priority surface water uses under the current conditions of the hydrologic regime, but was not an assessment of injury. It is well known that the hydrologic regime of the Eastern Snake Plain Aquifer has been enhanced by the widespread irrigation of lands above the aquifer. Whether or not impacts to a particular senior appropriator in a hydrologic regime enhanced by the historic water use of other appropriators fully constitutes injury is an issue that needs to be considered. Any diversion of water from either a ground water source or a surface water source can impact other diverters, but such impacts do not always constitute injury. Regardless of the extent that estimated impacts constitute injury, the Upper Snake River Basin Study did not include a study element to provide a basis for distributing the impacts to specific zonal groupings of wells.

Given these and other "gaps" between the knowledge gained from the Upper Snake River Basin Study and the level of knowledge needed to formulate appropriate mitigation plans, additional studies of the interaction between ground water and surface water, and the effects of ground water withdrawals and recharge, need to be performed. Perhaps some believe that the $287,000 expended to perform the Upper Snake River Basin Study should have been sufficient. Others might believe that the "gaps" cannot be closed without the development of a real-time decision support system for the Snake River Basin. The development of a real-time decision support system similar to that which will probably be developed eventually for the Snake River Basin is well under way for the Colorado River Basin at a cost thus far in excess of $5,000,000 and an expenditure of at least another $3,000,000 anticipated. While development of a decision support system for the Snake River Basin would clearly benefit the resolution of conflict over water use, complete development of such a system in the immediate future is not feasible. In particular, the time required to develop a real-time decision support system for the Snake River Basin is not compatible with the urgency of providing an improved basis for planning mitigation. Nonetheless, analytical evaluations beyond those performed during the $287,000 study effort funded thus far need to be accomplished.

Specifically, the following 10 additional study tasks need to be completed:

1. The input data from the existing two-dimensional model need to be transferred to an appropriate three-dimensional model and studies conducted to evaluate how sensitive analytically

predicted results are to three-dimensional effects. Although the data do not exist to fully describe the hydrogeologic characteristics of the Eastern Snake Plain Aquifer in three dimensions, it is important to determine whether three-dimensional effects could be significant in estimating the effects of ground water withdrawals and recharge.

2. Beginning with the existing model, estimates of the effects of aggregated ground water withdrawals within geographic units having appropriate zonal boundaries need to be made. This will begin to allow delineation of which groupings of wells have the greatest effect on specific senior surface water appropriators.

3. Defined objectives need to be established to provide focus for future recharge efforts and to provide a basis for measuring the effectiveness of managed recharge. While the following objectives may not be exclusive, meeting these objectives should provide meaningful improvement in the availability of water to fill existing water rights for the use of both surface and ground waters: (a) increase spring flows tributary to American Falls Reservoir; (b) increase spring flows discharging to the Thousand Springs reach of the Snake River; (c) stabilize ground water levels in the Jefferson County region; (d) stabilize ground water levels under the A & B Irrigation District; and (e) stabilize ground water levels under that portion of the Southwest Irrigation District over the Eastern Snake Plain Aquifer.

4. Identify alternative sites and prepare preliminary designs for infiltration basins that could provide for recharge that would meet the objectives defined above, or others that may be added or substituted, and would provide recharge capacity (individually or collectively) on the order of 500,000 acre-feet annually, assuming water would be available without injuring existing water rights, including those for minimum stream flows, at least during some years.

5. Develop preliminary designs for diversion and conveyance facilities that could divert and transport water from the Snake River and its tributaries to the alternative recharge sites which would meet the defined objectives.

6. Prepare preliminary cost estimates for constructing alternative recharge projects that would meet the defined objectives.

7. Conduct preliminary environmental investigations for the alternative recharge projects to identify potential environmental enhancements or detrimental effects to other environmental resources, such as water quality.

8. Identify the most feasible alternatives for managed recharge based on capability for meeting defined objectives, costs, and environmental effects.

9. Develop a method for accounting for water contributed by Idaho through managed recharge towards flow augmentation for salmon migration and habitat enhancements for other threatened or endangered species.

10. Determine the most appropriate process for authorizing recharge under existing or new water rights, including who holds the water rights and how benefits are determined and credited.

The primary goal of this additional study and evaluation is to identify which groups of junior ground water appropriators are potentially responsible for mitigating injury to particular senior surface water appropriators. The secondary goal is to identify which alternative projects for managed recharge would be most effective and feasible for mitigating injury. To the extent injury is established or agreed upon, junior ground water appropriators would be expected to implement the identified projects for managed recharge at their own cost through established ground water districts, new ground water districts, or through other appropriate means.

In some instances, for example situations involving injury to senior appropriators such as the North Side and Twin Falls Canal Companies who rely on spring flows tributary to American Falls Reservoir, it will be more effective for junior ground water appropriators to provide mitigation water directly to American Falls Reservoir, or other reservoirs, than to use water available for mitigation in a recharge project. While some recharge will still likely be necessary (see following discussion of mitigation wells), providing mitigation water for delivery directly out of existing reservoirs would provide direct compensation to the senior water right holders injured by reduced tributary spring flows. When available, mitigation water could be provided by leasing water from the water bank. In some instances, storage water leased from the water bank as mitigation for injury to senior rights for direct or natural flow could have been placed in the water bank by those same senior appropriators. In such cases, the senior appropriators benefit from using storage water leased by junior ground water appropriators from the water bank in lieu of storage water not placed in the water bank because the latter can be carried over for use during future drought periods and compensation has been made by the junior appropriators for the storage water provided through the water bank.

Eventually, there will be dry-year sequences during which: (a) direct or natural flows in the Snake River are not sufficient to fill the rights of senior appropriators; (b) those senior appropriators do not have sufficient storage water to provide for their necessary water supply; and (c) water is not available for lease from the water bank. During such dry-year sequences, it would not be consistent with the prior appropriation doctrine and Idaho's constitution and statutes for junior appropriators of ground water from an unconfined aquifer to have a full water supply while the water rights for senior surface water appropriators which rely on discharges to the river from the same unconfined aquifer could not be met. Hypothetically, mitigation during such a dry-year sequence could be offered to the senior appropriators for irrigation uses in the form of cash payments for loss of crops, reduction in crop yields, or even dry-year fallowing. Since the senior appropriator is not bound to mitigation in the form of cash payments, an alternative form of mitigation could be to fallow previously agreed upon acreage under ground water irrigation, and the ground water that would have been supplied to the fallowed acreage could be pumped to supply mitigation water to the senior appropriator (mitigation wells). Some might question the concept of depleting a reduced supply of ground water, as measured by decreased spring discharges, to provide mitigation for injury to surface water supplies already reduced by diminished spring flows. However, these depletions could be countered over the long term through managed recharge. Obviously, there are numerous issues, such as how water would be delivered from mitigation wells for use by senior appropriators, that require further consideration before this approach could be viewed as feasible. Nonetheless, this concept for mitigation is consistent with the prior appropriation doctrine and Idaho laws.

All of the preceding require knowledge of the water resources of the Upper Snake River Basin and the interaction between ground waters and surface waters. Perhaps even more important to the successful conjunctive management of these resources is productive collaboration between all the users that rely on the continued viability of the surface and ground water resources and with the managers of these publicly-owned resources. For the junior appropriators, it is important that they respect the rights of the senior appropriators. For the senior appropriators, it is important they respect the constitutional provisions which allow for optimal use of these resources which are the property of the state. For the managers of these resources, we must continue to develop innovative ways to manage and resolve conflicts between legal uses in accordance with the rights and priorities granted for those uses.

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APPENDICES A-F

APPENDIX A: TECHNICAL COMMITTEE STUDY ELEMENTS

Effects of Existing and Potential Changes in Water Use and Management

1. SNAKE RIVER WITHIN WATER DISTRICT 01

A. Review IDWR/UI GW Model Inputs. Prepare GIS data layers showing irrigated acres, by surface and sprinkler, in Non-Trust area.

B. Generate Base Study - Provide to Idaho Technical Committee on Hydrology (ITCH) for Review and Comment

C. Model Run with GW in Trust and Non-Trust areas deleted. Compare river gains and losses in Shelley to Blackfoot reach and Blackfoot to Milner reach to Baseline conditions. Compute effects on natural flows under equilibrium conditions.

D. Model run with changes from gravity to sprinkler of surface irrigated lands in the Trust and Non-Trust area deleted. Show changes in GIS data layer. Compare river gains and losses in Shelley to Blackfoot reach and Blackfoot to Milner reach to Baseline conditions. Compute effect on natural flows under equilibrium conditions. **Model run with surface water diversion rates at mid-1970's levels to show the effect of efficiency improvements which have been accomplished since that time. Compare river gains/losses to those under 1989 base conditions.**

E. Model run with potential new development in Non-Trust area added. Show additions in GIS data layer for surface and groundwater use. Compare river gains and losses in Shelley to Blackfoot reach and Blackfoot to Milner reach to baseline conditions. Compute effect on natural flows under equilibrium conditions.

F. Review the line of separation of ground water between trust and non-trust areas based on data collected since the original line was drawn.

G. Generate Time-Response curves for all model runs. Estimate the percent toward equilibrium under present conditions.

H. Estimate an effect on natural flow deliveries to TF&NS Canal Companies and others due to existing ground water use in the non-trust area.

I. Review and evaluate the procedures and data used to calculate the natural flow rights for the TF&NS Canal Companies. Prepare a report which describes the procedures.

J. Set up a system for use by Water District 01 in accounting for effect of GW use in Non-Trust area on natural flow rights of TF& NS Canal Companies and others. Formulate plan for GW users in Non-Trust area to compensate TF&NS Canal Companies using conjunctive management.

K. TOTAL STUDY COST FOR SNAKE RIVER WITHIN WATER DISTRICT 01 STUDY ELEMENT IS ESTIMATE TO BE ABOUT $97,000.

2. MAJOR TRIBUTARIES WITHIN WATER DISTRICT 01

L. Identify major tributary areas where surface water users may be significantly affected by ground water uses. Prepare a Plan of Study showing cost and issues for each potential study area.

M. THE ESTIMATED TOTAL COST FOR <u>IDENTIFYING</u> THE NUMBER OF STUDY AREAS AND PREPARING THE PLAN OF STUDY FOR EACH OF THE STUDY AREAS IS ESTIMATED TO BE $20,000.

3. SNAKE PLAIN AQUIFER

N. Prepare GIS data layers which identify ground water and surface water use under Baseline conditions. Compare to adjudication claims data to identify potential data problems.

O. Evaluate impacts of model studies with all groundwater irrigation on Snake River Plain deleted. Show this using GIS data layer. Compare river gains and losses throughout the system to Baseline conditions.

P. Model run to evaluate possible future changes from gravity to sprinkler of surface irrigated lands in the Trust and Non-Trust area deleted. Show changes in GIS data layer. Compare river gains and losses to Baseline conditions.

Q. Evaluate impacts of model studies with all changes in surface irrigation from gravity to sprinkler deleted. Show this using GIS data layer. Compare river gains and losses throughout system to Baseline conditions.

R. Run GW Model with potential new irrigation on Snake Plain Aquifer. Show this using GIS data layer. Compare river gains and losses throughout system to Baseline conditions.

S. Incorporate additions GW Model runs for alternatives identified through the IWRB study process. Prepare report on the hydrologic, economic, and environmental impacts of the different alternatives.

T. TOTAL STUDY COST FOR THE SNAKE PLAIN AQUIFER STUDY ELEMENT IS ESTIMATED TO BE ABOUT $125,000.

4. ENVIRONMENTAL CONCERNS

U. Cooperate with IWRB Middle Snake Study, IWRB Snake Plain Aquifer Study, US F&WL Service Endangered Species Studies, and DEQ Water Quality Studies in evaluating alternatives effecting the management and use of Snake River and spring flows for improving water quality and other environmental values.

V. ESTIMATED TOTAL COST FOR ADDRESSING ENVIRONMENTAL CONCERNS IS ABOUT $35,000

5. ARTIFICIAL RECHARGE

W. Review/evaluate data and information on recharge projects and prepare Plan of Study for a Recharge Project.

X. ESTIMATED TOTAL COST FOR ADDRESSING ARTIFICIAL RECHARGE IS $10,000

APPENDIX B: IDWR/UI ESPA GROUND WATER FLOW MODEL - GENERAL OUTLINE

CALCULATION PROCEDURE

Two dimensional
Block-centered, finite-difference
Iterative alternating direction-backward difference equation
Cartesian coordinate system-rectangular fixed grid
Selectable timestep
Leakage from overlying or to underlying water-bearing unit

CAPABILITIES

Steady state or transient(changes in head and flow with time)
Confined or unconfined aquifer or combinations
Model boundaries-fixed-head or fixed flux
Fixed head-time and location variable
Hydraulically connected rivers or drains
Fixed flux-underflow or zero-flux(impermeable)

PARAMETER ESTIMATION

Automatic on hydraulic conductivity, storage coefficient, leakance
Comparison of simulated to measured heads at each cell
Iterative procedure based on estimates of initial parameter(s) to be calibrated
Least-squares best-fit routine to minimize total sum of squares of differences between simulated and reference head values at each cell for each reference timestep
One parameter adjusted at a time
Parameter adjustments controlled by dampening factors

GROUND WATER MODEL INPUT

Grid parameters (interval, rows, columns)
Output specifications
Type of simulation
Type of aquifer system, timestep data

Calibration parameters, output mode
Reference timestep designations
Parameter calibration limits
River reach and cell groups (drains, rivers)
Initial parameters for each cell (K, leakance, S)
Cell type identifiers (outside, fixed head, basic node, fixed flux, confined, thickness, land surface elevation, aquifer bottom elevation, initial potentiometric surface)

RECHARGE PROGRAM

Data management routines to generate ground water model flux for each cell for each timestep

1. Seepage from canals
2. Recharge from surface water supplied irrigation
3. Pumping for irrigation or other (based on vegetation ET and soil moisture retention or supplied)
4. Recharge from precipitation
5. Gains and losses from rivers or lakes
6. Underflow across model boundaries

Recharge (+) or discharge (-) from each node is calculated as the residual in the water balance for each node for each timestep. The equation is:

$$Q = SEEP + (irr + rain - ET - soil) + WELL + RIVER + UNDER$$

SEEP	=	canal seepage
irr	=	surface water irrigation
rain	=	effective precipitation
soil	=	change in soil water content
WELL	=	pumping withdrawals
RIVER	=	river gains or losses
UNDER	=	ground-water underflow

Canal seepage is based on canal wetted area per node and seepage rate based on soil type or measured data. Each canal in each node is coded to a specific irrigation district or canal company which diverts from the river or stream and either serves lands in the cell or passes through the cell.

Canal seepage can either be calculated separately or lumped with surface irrigation water. Canal seepage can be changed during a simulation to represent changes in operation or canal lining.

The diversions and river return flows are coded by irrigation district or canal company and recorded diversions per time step input to an array. Recharge occurs only when irrigation application plus effective precipitation exceeds ET plus soil moisture storage. Irrigated areas for ground-water and surface water are delineated in each cell. The modeled area is divided into climatic zones in which crop ET, precipitation, and irrigation management are assumed to be similar. ET is calculated as the product of a reference crop ET and a crop coefficient which is time dependent.

Recharge on non-irrigated areas is calculated using a water balance similar to the irrigated areas except that ET is different and no irrigation water is applied.

Ground water pumping is normally calculated as the crop consumptive use for the ground water irrigated area in each cell. Any pumping in excess of ET is assumed to return to the aquifer in the same timestep as the pumping occurred.

Effective precipitation is defined as that percentage of measured precipitation and/or snow melt which reaches the aquifer through deep percolation. Effective precipitation in climatic zones is defined in the program.

Extraction (pumping) from any aquifer can be specified by well. Normally, this routine is used to designate well pumping for other than irrigation or where the withdrawal is from a confined system where excess pumping for irrigation does not recharge the aquifer.

River gains and losses (fixed) are input by timestep for cells or groups of cells. This is normally based on historically measured reach gains. Underflow from tributary valleys is handled in the same way by distributing calculated ground water underflow over a group of cells.

LIMITATIONS AND ASSUMPTIONS

The program, although general, is limited by physical conditions and assumptions. A list of the major limitations and assumptions follows.

1. Recharge occurs in the same timestep as application, that is, no time is provided for movement through the unsaturated zone.
2. No significant lateral flow occurs above the water table in the unsaturated region.
3. The aquifer is unconfined (unless inputs are adjusted accordingly).
4. Ground-water irrigation occurs at rates sufficient to meet crop demands.
5. Ground-water irrigation occurs only between the dates specified by the user.
6. Irrigation supplies sufficient water to allow crops to transpire at their potential.
7. Irrigation application rates within a project are uniform.
8. Weather, agricultural practices, and soil properties are constant within a climatic region.
9. No significant amount of crops other than alfalfa, winter and spring grain, sugar beets, beans, peas, corn, potatoes, or pasture is grown.
10. The crop coefficients determined at Kimberly, Idaho are representative of the study area.
11. Evapotranspiration from alfalfa is proportional to yield.

12. The length of a timestep is neither too long nor too short to cause errors in the calculation of ET, according to the criteria described in "Algorithm Description."
13. Precipitation does not result in runoff.
14. River or creek gains or losses are uniform along a specified reach.
15. Underflow is uniform along a specified reach.

Deviations from the above assumptions require appropriate changes within the program.

APPENDIX C: ESPA MODELED AREA IRRIGATED ACREAGE

The ground water model studies completed for this investigation are based on estimates of irrigated acreage overlying the ESPA. Irrigated acreage is used in the water balance of the aquifer system to compute, 1) the location and volume of water lost from evapotranspiration (a discharge term) overlying areas irrigated from ground water pumping, and 2) the location and volume of excess seepage (a recharge term) overlying areas irrigated from surface sources. Accurate estimates of surface and ground water irrigated areas for both model calibration and present (base study) conditions are necessary for accurate study results. Described in this appendix are the methods used to arrive at these estimates for 1980 irrigated acres, which was used to calibrate the model, and for 1992 irrigated acres, which was used to complete the base study and all "what if " studies.

1980 IRRIGATED ACREAGE

The layer of irrigated acreage for 1980 was generated as part of a cooperative project with the USGS. This project is documented in detail in USGS Professional Paper 1408-E, "Water Use on the Snake River Plain, Idaho and Eastern Oregon"(Goodell, 198?).

The acreage was generated by computer processing Landsat MSS data covering the Eastern Snake Plain. The method used is described in an IDWR report, "1980 Inventory of Irrigated Cropland on the Snake River Plain" (Anderson, 198?). The report states that "A stratified random sampling design was used to insure representative data for the entire study area. Training statistics for land-cover classification were developed using a maximum-likelihood classifier in a modified clustering approach. A simple linear regression was conducted to determine the relationship of Landsat data to ground data." The regression relationship was used to correct Landsat acreage values based on the ground measured acreage by stratum.

1992 IRRIGATED ACREAGE

The layer of 1992 irrigated acreage for the modeled area was generated from two sources. The majority of the layer came from cooperative mapping done by IDWR and the USBR in 1990 through 1992. Three small areas (<10 square miles) were taken from a 1987 classification of Landsat satellite data. A description of the Landsat classification is found in the article, "Using Remote Sensing and GIS Technology to Help Adjudicate Idaho Water Rights" (March, 1990).

In 1990, personnel from the USBR began mapping irrigated agriculture on the Eastern Snake Plain. The project was designed specifically to map the method of irrigation: sprinkler or flood. The method involved using aerial photography taken in 1987 to map irrigated fields. The 1987 data were verified and updated by field checks in 1991-1992. The photography was 1:40,000-scale color infrared. The method was as follows: 1) reduce 1:24,000-scale quadrangle maps to 1:40,000; 2) overlay the quad maps on the photography and locally register the map to the image; 3) trace field boundaries and label fields as irrigated (by sprinkler or flood) or non-irrigated; and 4) field check the boundaries and labels. The 1992 final irrigated lands over the ESPA is shown by Figure C1.

GROUND AND SURFACE WATER IRRIGATED ACRES DISTRIBUTION

The acres identified by the USBR were then categorized as ground water or surface water irrigated. Accurate determination of water source is important in studies which involve assessing the impact on the aquifer and spring discharges of ground water pumping. Estimating changes the historical pattern of ground water development is accomplished by removing these acres and their consumptive use in the model.

For each one mile section inside the ESPA model where irrigated acres were identified, the IDWR water rights data base was overlaid and a ratio of surface water right acreage to ground water right acreage developed for each section. The mapped acres were proportioned in each section to ground and surface water irrigated based on the computed ratio. The acres were summed by model node as surface water acres or ground water acres. The surface water acres were then assigned to service areas so that they could be related to measured canal diversions delivered to that service area. Figures C2 and C3 show the proportional distribution of surface and ground water acres by model cell for 1980 and 1992, respectively.

Table C1 includes acreage summaries for the 1980 and 1992 irrigated acres used in the ESPA model. Ground water and surface water acres were adjusted to account for non-irrigated portions of the identified acres (farmstead, roads, infrastructure).

APPENDIX C REFERENCES

Anderson, H.N., 1983, 1980 Inventory of Irrigated cropland on the Snake River Plain, Unpublished Report, Idaho Image Analysis facility of the Idaho Department of Water Resources, 31 p.

Goodell, S.A., 1988, Water Use on the Snake River Plain, Idaho and Eastern Oregon: U.S. Geological Survey Professional Paper 1408-E, 51p.

Table C1. Surface and Ground Water Irrigated Acres Over Modeled Area of the ESPA

Year	Ground Water Acres	Surface Water Acres	Total Acres	Adjusted Groundwater Acres[1]	Adjusted Surface Water Acres[2]	Adjusted Total Acres
1980	793,184	915,615	1,708,799	753,524	778,272	1,531,797
1992	860,920	718,926	1,579,846	817,874	611,087	1,428,961

[1] Multiply by 0.95 to adjust ground water acres for non-irrigated portions

[2] Multiply by 0.85 to adjust surface water acres for non irrigated portions

Figure C1

Eastern Snake Plain Aquifer Irrigated Lands from the 1992 USBR Classification

Upper Snake Model

Eastern Snake
Plain Aquifer

Irrigated Lands

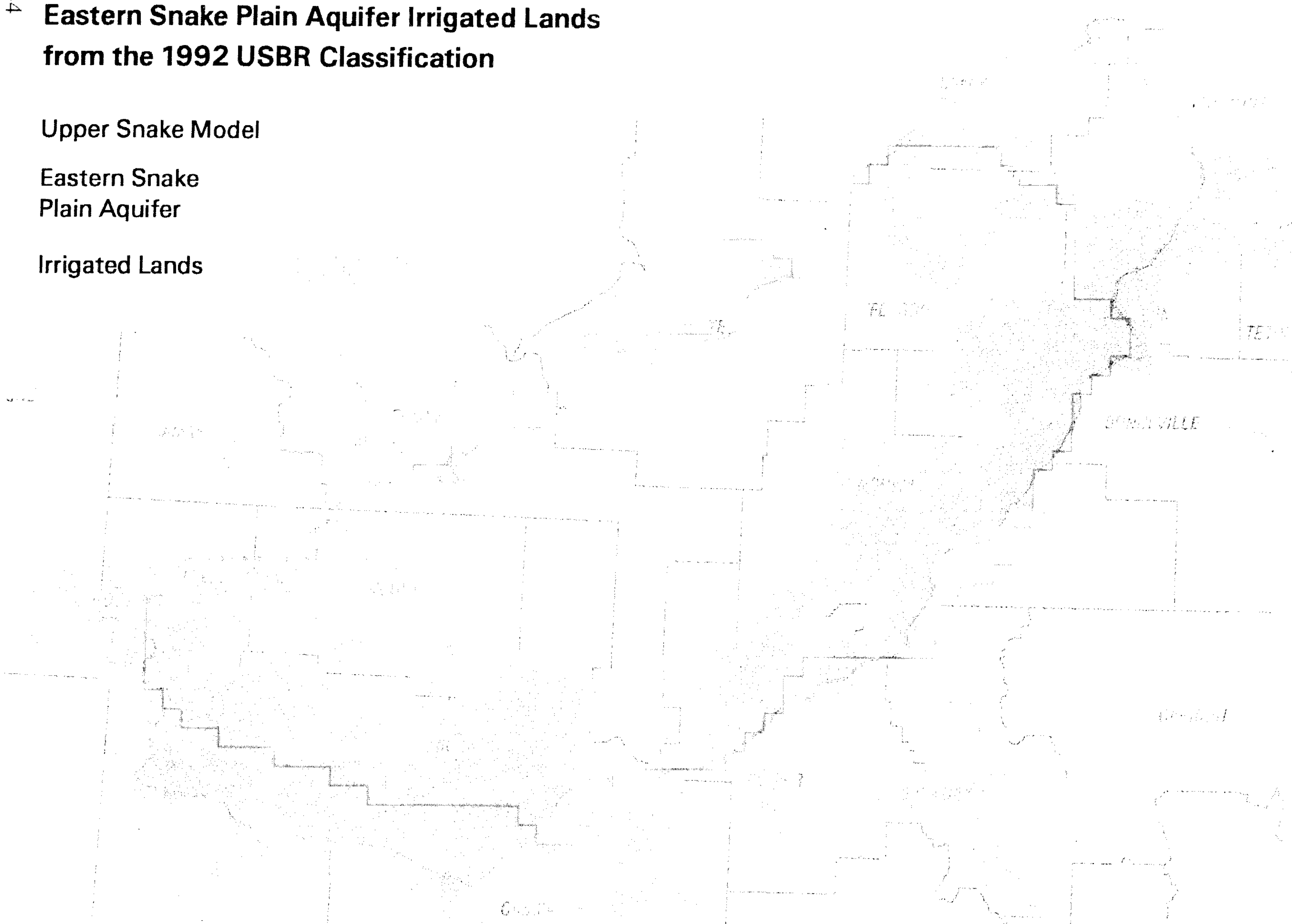


Figure C2

ESPA Ground Water Model: Proportion of Irrigation Source by Model Cell (1980)

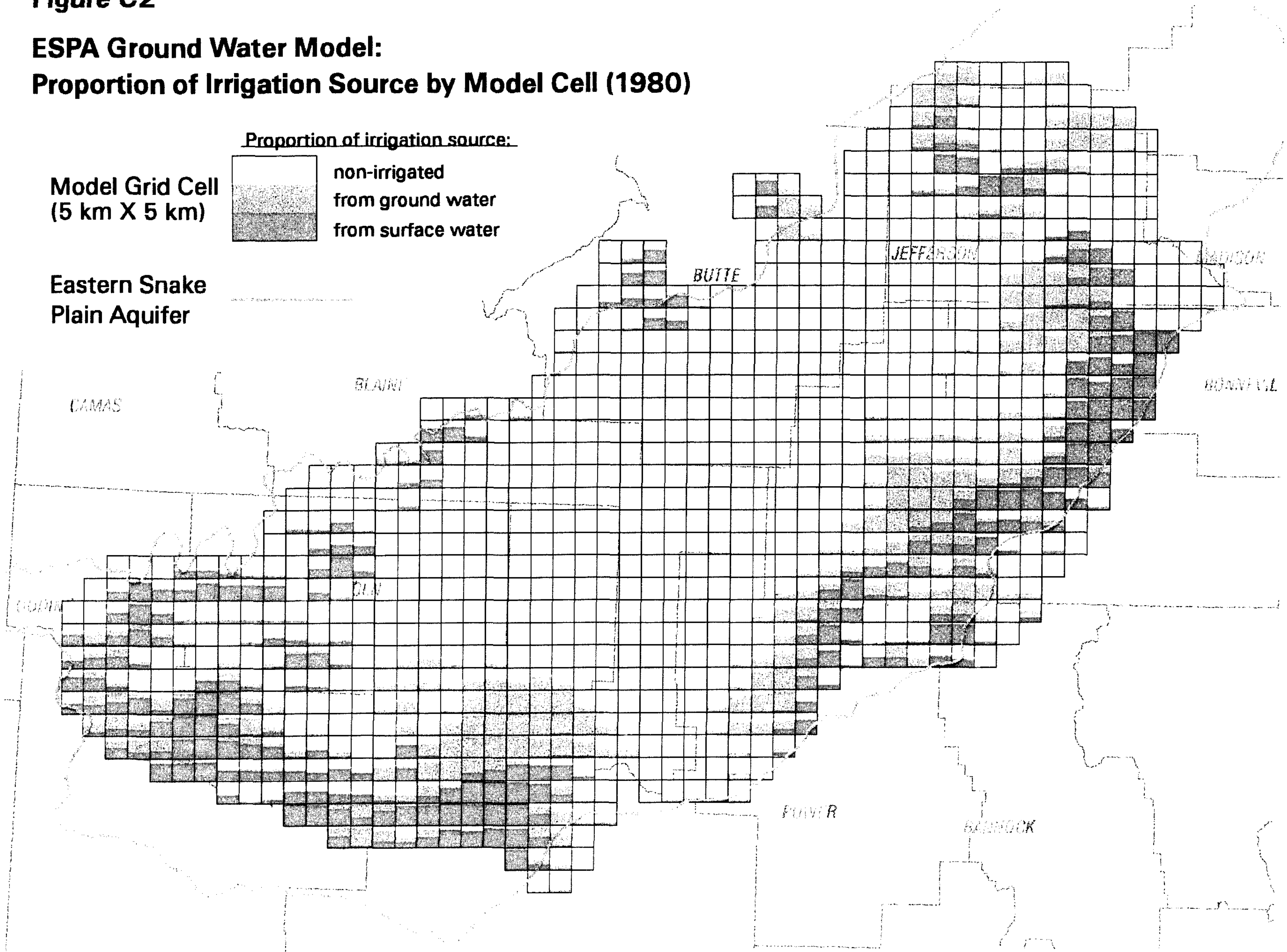
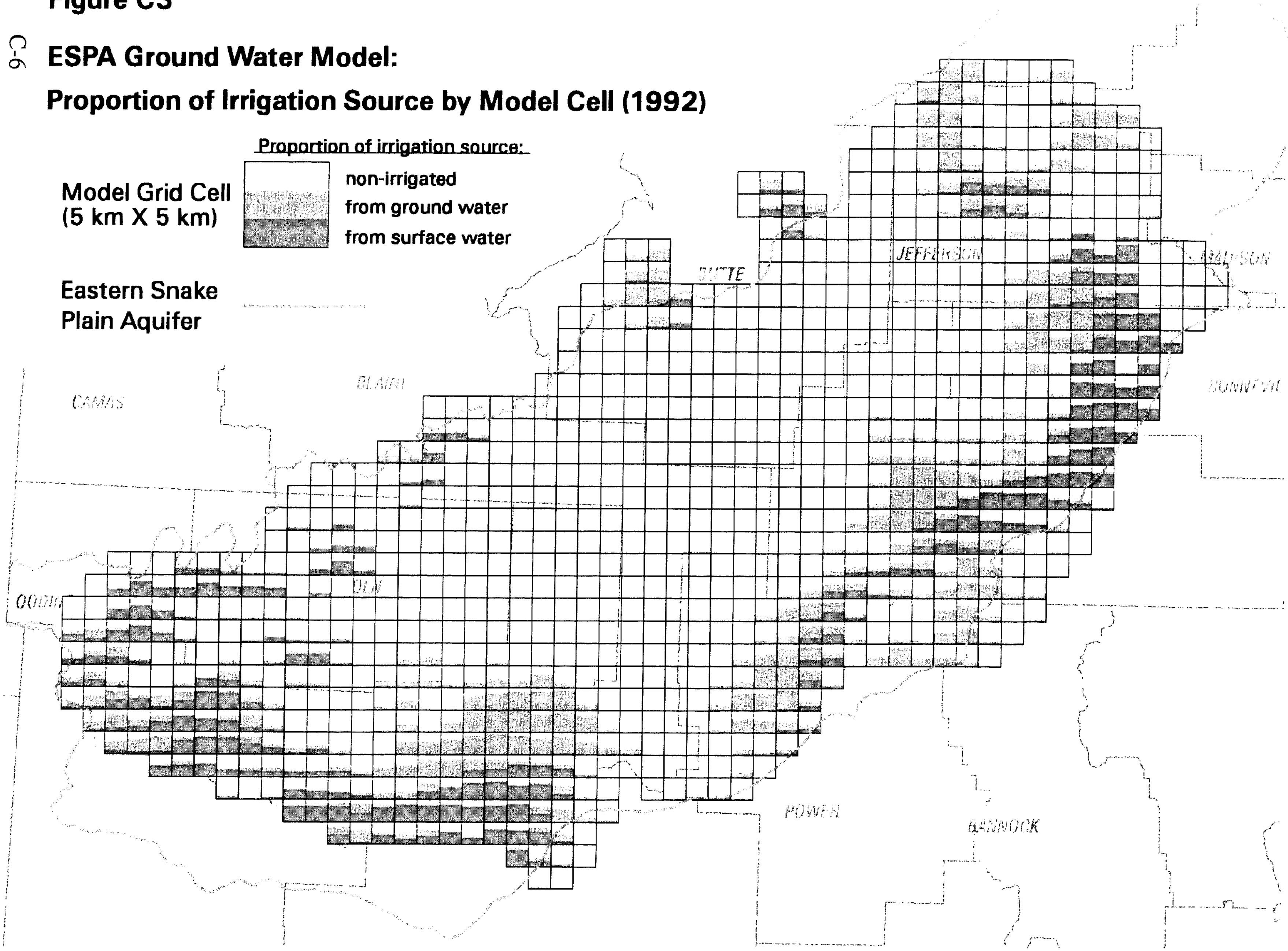


Figure C3

ESPA Ground Water Model:

Proportion of Irrigation Source by Model Cell (1992)



APPENDIX D. ESPA RECHARGE FROM THE HENRYS FORK AQUIFER

The ESPA receives substantial recharge (leakage) from the perched aquifer system overlaying the ESPA in the Henrys Fork and Rigby Fan area. The ESPA ground water model developed by IDWR and UI originally accounted for leakage from the Henrys Fork/Rigby Fan Aquifer (HFA) by adding a predetermined input value for each timestep for each underlying node. These values, which remained constant for each cycle (year), were estimated from a separate ground water flow model developed by UI (Wytzes, 1980 and Johnson, et al., 1985) for the HFA system. The HFA model accounts for leakage between the systems by assuming a constant ESPA head. The HFA modeled area and its overlap with the ESPA model is shown in Figure D1.

Actual leakage from the HFA to the ESPA is dependent on hydraulic heads in both aquifers. An increase in ESPA heads reduces the leakage from the HFA, and conversely, a decrease in ESPA heads increases the leakage from the HFA. However, due to the method of inputting the constant HFA leakage into the ESPA model impact of varying heads could not be simulated. A method was needed to simulate the leakage between the two aquifers under varying head differences when simulating a "what if" condition on the ESPA.

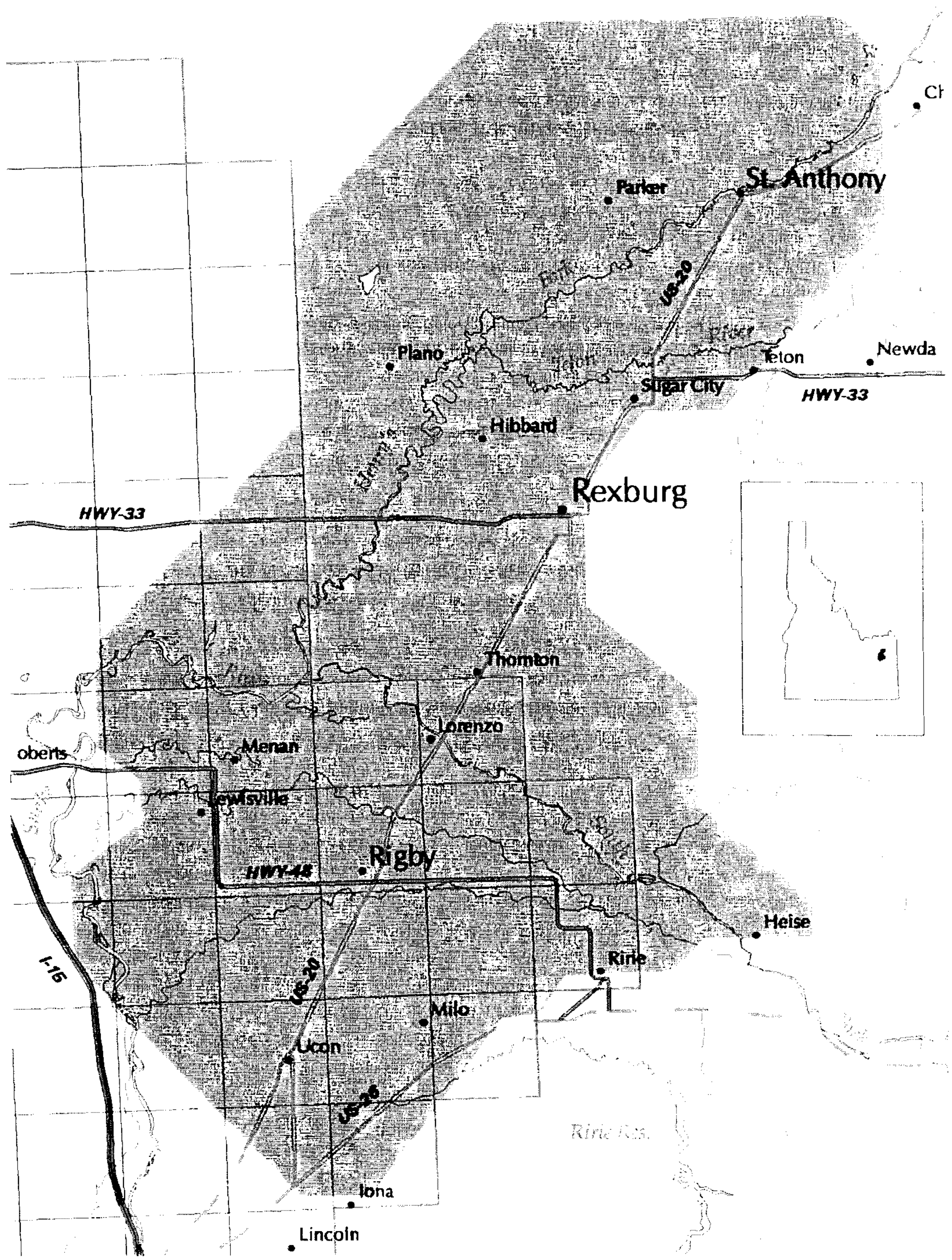
The ESPA model was modified to allow for head dependent leakage by using the HFA model to compute leakage over a range of head differences. Relationships between leakage and head differences were then developed.

PROCEDURE

The ESPA model was modified to incorporate head dependent leakage input values from the HFA by individual node or groups of nodes. Analysis of the change in leakage from the HFA (perched) system due to head changes in the ESPA (regional) system indicated that as the regional heads decreased the leakage would increase until the regional heads were below the aquitard separating the aquifers. Once the regional heads decreased below that level, the leakage would be a function of only the perched system heads regardless of the regional head. With regional heads above the aquitard separating the aquifers, the leakage from the perched system would be inversely proportional to the regional heads. When the regional heads exceed the perched system heads, the direction of flow between systems changes from recharge of the regional system to discharge from the regional system.

Figure D2 illustrates the functional relationship between leakage and regional system piezometric heads at each node. The portion of the relationship for regional heads above the aquitard should be linear; however, realizing that spatial effects (neighboring nodes) might induce non-linearity, the head dependent relationship incorporated into the ESPA model became non-linear with a lower limit corresponding to the point where the regional system drops below the aquitard.

Figure D1. Henry's Fork - Rigby Fan Model Area



5K Model Cell Size (ESPA Model Boundary)

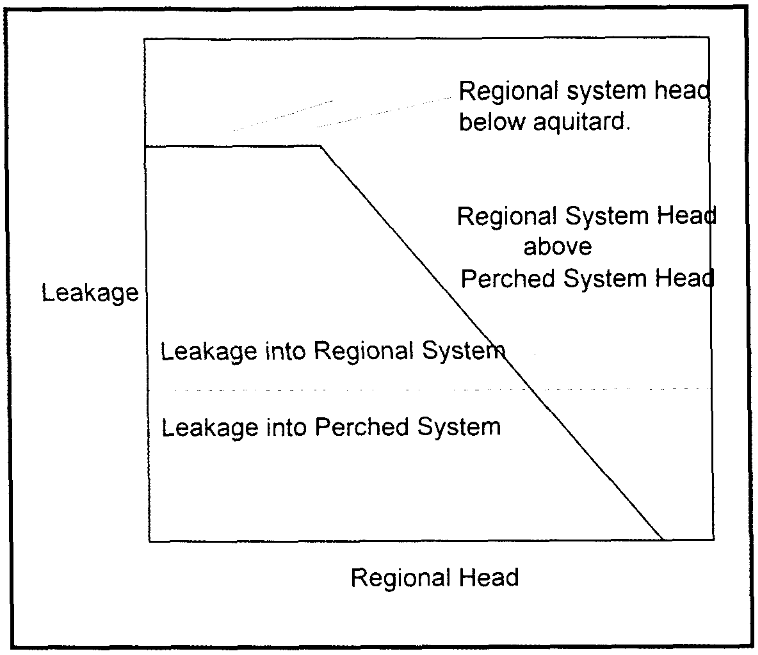


Figure D2. Leakage as a Function of Regional Heads

To develop the head to leakage relationship between the HFA and the ESPA, ten simulations were made utilizing a range of head differentials for 30 year periods. Johnson's single year calibration data set was extended to cover the 30 year period with bimonthly time steps. Changes in head differentials were applied uniformly across the HFA. The only exception was that the head differential was not changed when it resulted in a regional head below the bottom of the HFA system. For each of the last twenty-four time steps, the simulated leakage by node was extracted to develop relationships between leakage and head differential. Utilizing year thirty leakage data set, a relationship was developed for each time step of each node relating change in leakage to change in ESPA piezometric heads. Table D1 summarizes the combined change in leakage from all nodes for the ten simulation runs for year thirty. Figure D3 displays the relationship between ESPA change in head and annual leakage.

Table D1. HFA Leakage Response to ESPA Head Change

Assumed ESP Piezometric Head Change (ft)	Change in Head Differential (ft)	Average Change in Head Differential (ft)	Annual Leakage (kaf)	Change in Annual Leakage (kaf)
+30	-30	-30	1,095	-477
+25	-25	-25	1,178	-394
+20	-20	-20	1,260	-312
+15	-15	-15	1,339	-232
+10	-10	-10	1,418	-154
+5	-5	-5	1,496	-76
0	0	0	1,572	0
-5	+5	+5	1,647	+75
-10	+10	+7.8	1,721	+149
-15	+15		1,793	+221

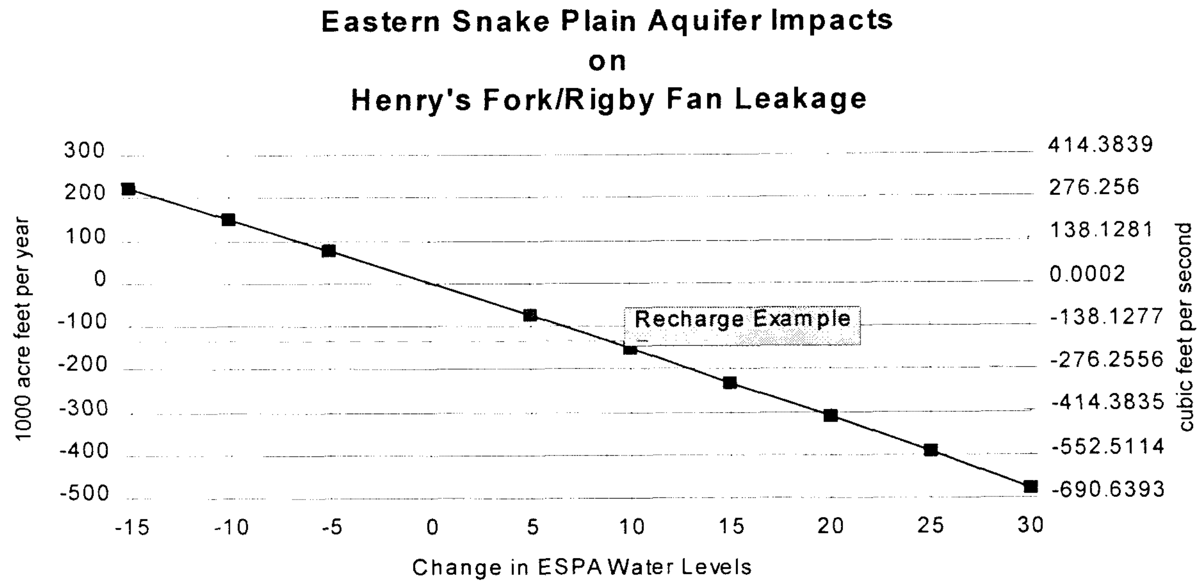


Figure D3. Change in HFA Leakage Due to ESPA Head Changes

The modified leakage from the HFA system results in potential changes in flows through hydraulically connected rivers and boundaries within the HFA modeled area. These locations are the Henrys Fork, Snake River and the Mud Lake area. Further examination of these showed change in surface discharge to the Mud Lake area to be insignificant. Therefore, flow changes were assumed to occur completely within the Henrys Fork and Snake River.

APPLICATION TO ESPA MODEL

The ESPA modeled area underlies only a portion of the HFA model (see Figure D1) Approximately 23 active ESPA nodes underlie the HFA model area. The HFA area overlies 35 non-active ESPA nodes. The base ESPA model's surface recharge term includes the leakage from the HFA distributed over the 23 active nodes with seven boundary nodes receiving the leakage associated with non-active nodes. On the basis of the original leakage distribution and similar heads, the 23 nodes were divided into 17 groups. For each group, the time step leakage coefficients were transformed to yield change in leakage as a function of absolute head instead of change in head.

Utilizing these 408 sets of equation coefficients, plus an additional 168 sets for boundary nodes, the ESPA model was modified to estimate change in recharge due to HFA leakage. To verify the accuracy of this method, a new base study simulation was made using the equation coefficient data sets. When compared to the original base study, no significant change in the computed HFA leakage occurred.

APPENDIX D REFERENCES

Johnson, G.S., C.D. Brockway, and S.P. Luttrell, 1985, Ground Water Model Calibration for the Henrys Fork Recharge Area: Idaho Water Resources Research Institute, University of Idaho, 18p.

Wytzes, J., 1980, Development of a Ground Water Model for the Henrys Fork and Rigby Fan area, Upper Snake River Basin: Idaho Water and Energy Resources Research Institute, University of Idaho, Moscow, Idaho, 205p.

APPENDIX E: MAJOR FEATURES OF IDWR WATER DISTRICT 1 WATER RIGHT ACCOUNTING PROCEDURE

1. Gains are computed to the river by reaches. There are 26 reaches in Water District 1 which are defined by stream gages. For each reach, gain is the sum of outflow plus diversions minus inflow. If there is a reservoir in the reach, the change in storage is added. Evaporation from the reservoir is also added unless it is a natural lake. Return flow from irrigation which may enter the river in the reach is not deducted from the gain because, for water distribution purposes, it is allocated as natural flow.

2. Natural flow in each reach is the sum of gains from the headwaters down to the reach end. Travel times are incorporated by offsetting the gains in appropriate reaches.

3. Natural flow is then allocated by priority. The allocation process begins with the oldest priority by subtracting the lesser of the right or the amount of the diversion from the natural flow at the end of its reach and all downstream reaches. This process is repeated successively in order of priority, regardless of location, resulting each time in a set of remaining natural flows (RNF) throughout the basin. When a zero RNF is computed, all natural flow in the basin above that point is allocated. When zero RNF occurs at the end reach (Milner), allocation is complete.

4. Diversions in excess of their allocated natural flow are diverting the excess from storage. If the diversion has no storage account or has used up its entitlement, it must rent additional storage water, or be reduced to its natural flow entitlement.

5. Accounting is run throughout the year to allow available natural flow to accrue to the correct reservoirs in accordance with their water rights. Storage is credited to a reservoir right if RNF is available to the reservoir priority in its reach, even if no water is stored there. This is done to avoid the accounting process from being a counter incentive to efficient management reservoirs as a group.

APPENDIX F: DETAILS PERTINENT TO EACH TRIBUTARY BASIN STUDY

UPPER HENRYS FORK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the upper Henrys Fork basin utilizing the method previously described. A study performed by Whitehead (1978) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics, depth to water, and streamflow reach gain and loss measurements. A field visit to the basin will provide information on estimates of the streambed characteristics of upper Henrys Fork and percentages of each ground-water irrigated crop. Due to the relatively small amount of ground-water development currently in the basin and the available data from previous studies, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

FALLS RIVER/CONANT CREEK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Falls River/Conant Creek basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water estimates of the streambed characteristics of Falls River and Conant Creek, and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three man-months and $18,000, respectively.

TETON RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Teton River basin utilizing the method previously described. A study performed by Kilburn (1964) will be the primary source of information on the hydrogeology of the upper portion of the basin. This report contains data on aquifer characteristics and depth to water. Aquifer characteristics for the lower portion of the basin will be acquired from driller's reports. A field visit to the basin will provide information on depth to water in the lower portion, estimates of the streambed characteristics of Teton River, streamflow reach gain and loss measurements, and percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin and the lack of available data, the time and cost to perform the proposed study are estimated to be six man-months and $36,000, respectively.

REXBURG BENCH

Surface water and ground water in the Rexburg Bench are <u>not</u> hydraulically connected, as is evident by Moody Creek (the principal drainage) being perched above the regional water table. As a result, the model created for this area will only simulate changes in underflow leaving the basin from ground-water withdrawal. The method that will be used is identical to what was previously described, except that there will be no surface water component included in the model.

Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the area will provide information on percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be four man-months and $24,000, respectively.

SOUTH FORK OF THE SNAKE RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the South Fork of the Snake River basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on estimates of the streambed characteristics of the South Fork of the Snake River, and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three man-months and $18,000, respectively.

WILLOW CREEK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Willow Creek basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water, estimates of the streambed characteristics of Willow Creek, and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three man-months and $18,000, respectively.

BLACKFOOT RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Blackfoot River basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water, estimates of the streambed characteristics of Blackfoot River, and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three man-months and $18,000, respectively.

PORTNEUF RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Portneuf River basin utilizing the method previously described. A study performed by Norvitch and Larson (1970) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics and depth to water. A field visit to the basin will provide information on estimates of the streambed characteristics of Portneuf River, streamflow reach gain and loss measurements, and percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin and the lack of available data, the time and cost to perform the proposed study are estimated to be six man-months and $36,000, respectively.

BANNOCK CREEK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Bannock Creek basin utilizing the method previously described. A study performed by Spinazola and Higgs (in review) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics. A field visit to the basin will provide information on depth to water, estimates of the streambed characteristics of Bannock Creek, streamflow reach gain and loss measurements, and percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin and the lack of available data, the time and cost to perform the proposed study are estimated to be four and one-half man-months and $27,000, respectively.

ROCKLAND BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Rockland basin utilizing the method previously described. A study performed by Williams and Young (1982) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics, depth to water, and streamflow reach gain and loss measurements. A field visit to the basin will provide information on estimates of the streambed characteristics of Rock Creek and percentages of each ground-water irrigated crop. Due to the relatively small amount of ground-water development currently in the basin and the available data from previous studies, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

RAFT RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Raft River basin utilizing the method previously described. Studies performed by Nace and others (1961) and Walker and others (1970) will be the primary sources of information on the hydrogeology of the basin. These reports contain data on aquifer characteristics and streamflow reach gain and loss measurements. A field visit to the basin will provide information on depth to water, estimates of the streambed characteristics of Raft River, and percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be five and one-half man-months and $33,000, respectively.

OAKLEY FAN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Oakley Fan area utilizing the method previously described. A study performed by Young and Newton (1989) will be the primary source of information on the hydrogeology of the area. This study included model simulations of the stream-aquifer system. The aquifer boundaries and properties, and stream-aquifer parameters used in their calibrated model will be directly input into the model that is developed from this study. A field visit to the area will provide information on percentages of each ground-water irrigated crop. Due to the available data from the previous modeling study, the time and cost to perform the proposed study are estimated to be only four man-months and $24,000, respectively.

CAMAS/BEAVER CREEK BASINS

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Camas/Beaver Creek basins utilizing the method previously described. A study performed by Spinazola (1994) will be the primary source of information on the hydrogeology of the area. This study included model simulations of the stream-aquifer system in the lower portions of these basins. The aquifer boundaries and properties, and stream-aquifer parameters used in his calibrated model will be directly input into the model that is developed from this study. A field visit to the basins will provide information on depth to water, estimates of the streambed characteristics of Beaver and Camas Creeks, and percentages of each ground-water irrigated crop. Due to the available data from the previous modeling study, the time and cost to perform the proposed study are estimated to be only four man-months and $24,000, respectively.

MEDICINE LODGE CREEK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Medicine Lodge Creek basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water estimates of the streambed characteristics of Medicine Lodge Creek, streamflow reach gain and loss measurements, and percentages of each ground-water irrigated crop. Due to the relatively large amount of ground-water development currently in the basin and the lack of available data, the time and cost to perform the proposed study are estimated to be four and one-half man-months and $27,000, respectively.

BIRCH CREEK BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Birch Creek basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water estimates of the streambed characteristics of Birch Creek and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three man-months and $18,000, respectively.

LITTLE LOST RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Little Lost River basin utilizing the method previously described. A study performed by Clebsch and others (1974) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics and depth to water. A field visit to the basin will provide information on estimates of the streambed characteristics of Little Lost River and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin and the available data from previous studies, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

BIG LOST RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Big Lost River basin utilizing the method previously described. Studies performed by Crosthwaite and others (1970) and Goodell and others (in review) will be the primary sources of information on the hydrogeology of the basin. Both reports contain data on aquifer characteristics, depth to water, and streamflow reach gain and loss measurements. The second study included model simulations of the stream-aquifer system in the lower portion of the basin. The aquifer boundaries and properties, and stream-aquifer parameters used in their calibrated model will be directly input into the model that is developed from this study. A field visit to the basin will provide information on estimates of the streambed characteristics of Big Lost River and percentages of each ground-water irrigated crop. Due to the available data from previous studies, the time and cost to perform the proposed study are estimated to be only four and one-half man-months and $27,000, respectively.

LITTLE WOOD RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Little Wood River basin utilizing the method previously described. Well driller's reports will provide the primary source of information on the aquifer characteristics. A field visit to the basin will provide information on depth to water estimates of the streambed characteristics of Little Wood River and percentages of each ground-water irrigated crop. Hydraulic conductivity of the streambed will be estimated from aquifer characteristics and compared with computed values for other tributary basins. Due to the relatively small amount of ground-water development currently in the basin, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

BIG WOOD RIVER BASIN

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Big Wood River basin utilizing the method previously described. A study in progress by Brockway and others will be the primary source of information on the hydrogeology of the area. This study will include model simulations of the stream-aquifer system. The aquifer boundaries and properties, and stream-aquifer parameters used in their calibrated model will be directly input into the model that is developed from this study. A field visit to the basin will provide information on percentages of each ground-water irrigated crop. Due to the available data from the current modeling study, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

CAMAS PRAIRIE

A stream-aquifer model will be created that will simulate the relationship between surface water and ground water in the Camas Prairie utilizing the method previously described. A study performed by Young (1978) will be the primary source of information on the hydrogeology of the basin. This report contains data on aquifer characteristics, depth to water, and streamflow reach gain and loss measurements. A field visit to the basin will provide information on estimates of the streambed characteristics of Camas Creek and percentages of each ground-water irrigated crop. Due to the relatively small amount of ground-water development currently in the basin and the available data from previous studies, the time and cost to perform the proposed study are estimated to be only three and one-half man-months and $21,000, respectively.

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